GULF CANADA RESOURCES LIMITED

FINAL REPORT

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BENEFICIATION AND ENLARGEMENT OF ANTHRACITE FINES

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SUMMARY

This cost-shared research contract between Gulf and CANMET evaluated froth flotation, oil agglomeration, and agglomeration flotation for beneficiating anthracite fines. Product characteristics from these processes are established and the general operating conditions for these processes are identified. The results of this study have provided an important data base for the beneficiation of Mt. Klappan anthracite fines.

Mt. Klappan anthracite fines responded favorably to froth flotation, oil agglomeration and agglomeration flotation. No processing difficulty was encountered when these surface chemistry dependent processes were applied to this high rank coal.

Many process variables were evaluated in this research contract. For froth flotation, it was found that glycol based frothers are most effective for anthracite fines. It was also found that fine particles (0.15 mm x 0) require substantially higher collector dosages than coarse particles (0.6 x 0.15 mm). Depending on the size consist of the feedstock, flotation of split size fractions offers an alternative for processing feedstock of full size consist.

High oil dosages are required for successful performance of the oil agglomeration process (>16.0 oil cut %). Bunker C produces stronger and larger agglomerates than diesel when used as a bridging liquid. Rewashing the strong agglomerates can significantly reduce the ash content of the upgraded product without excessive carbon loss.

Agglomeration flotation permits the operation of the oil agglomeration process at significantly lower dosage of bridging liquid (5 kg/t). The high shear mixing during the agglomeration process also allows the use of heavy oil, such as Bunker C, to function as a collector in the subsequent flotation process.

Product characteristics for feedstocks of 0.6 mm x 0 and 0.15 mm x 0 from the three different processes are summarized below. Clean coals of satisfactory recoveries and significantly reduced ash contents are produced under optimum processing conditions. Carbon recoveries range from 85% to 96% under the optimum processing conditions. While froth flotation can produce acceptable products at low dosages of collector (1.0-5.0 kg/t), the performance of the agglomeration flotation process is only acceptable at a higher bridging liquid/collector level (5.0 kg/t). Good performance is observed for the oil agglomeration process only at very high dosage of bridging liquid (> 160 kg/t). The data from this study indicates that froth flotation presents itself as the most likely candidate for beneficiating Mt. Klappan anthracite fines.

Summary of Product Characteristics of Mt. Klappan Anthracite Fines Beneficiated by Froth Flotation, Agglomeration Flotation, and Oil Agglomeration

Particle Size	Method	Collector/ Bridging Liquid	Dosage (kg/t)	Clean Coal		Tailings		Feed Ash % (Reconst)	Carbon Recovery %
				Yield %	Ash %	Yield %	Ash %		
0.6 mm x 0	Froth Flotation	Diesel	1.0	63.5	8.3	36.5	43.9	21.3	74.0
	Froth Flotation	Diesel	5.0	79.2	10.2	20.8	62.7	21.1	90.1
	Agglomeration Flotation	Diesel	5.0	84.7	11.9	15.3	77.6	21.9	95.6
	Oil Agglomeration	Bunker C	160	83.8	9.7	16.2	81.3	21.3	96.2
0.15 mm x 0	Froth Flotation	Diesel	2.3	68.7	15.1	31.3	67.6	31.5	85.2
	Agglomeration Flotation	Diesel	10.0	76.0	17.8	24.0	80.8	32.9	93.1
	Oil Agglomeration	Bunker C	200	63.0	8.2	37.0	75.3	33.0	86.3

1.0 INTRODUCTION

This report describes work performed during 1988 on D.S.S. Contract 030.SQ.23440-8-9045, "Beneficiation and Enlargement of Anthracite Fines."

Froth flotation, oil agglomeration, and agglomeration followed by flotation were evaluated as beneficiation methods for anthracite fines. Flotation is used in many preparation plants for fine coal cleaning and oil agglomeration offers potential as well as enlarges particle size. Flotation could be a practical method for separating the clean coal and rejects obtained in the agglomeration process.

There is little operating data in applying these methods for anthracite fines. In addition, the low hydrogen to carbon ratio of anthracite may necessitate different process conditions than for bituminous coals. A literature survey was therefore performed to search for information which may help to define the general experimental conditions. The effects of process variables were studied in each case to arrive at the optimum process conditions.

The research contract consists of six tasks with the following specific objectives:

1. To carry out a literature survey on anthracite fines beneficiation by froth flotation and oil agglomeration.
2. To characterize the Mt. Klappan anthracite fines used in this study.
3. To study the effect of process variables in froth flotation and produce a clean coal at optimum conditions.
4. To study the effect of process variables in oil agglomeration and produce a clean coal at optimum conditions.
5. To study froth flotation as a method for separating clean coals and rejects obtained from oil agglomeration.

The results of this research contract are discussed in detail in this Final Report. The work statement of this research contract is shown in Appendix 1.

2.0 LITERATURE REVIEW

The primary objective of the literature review was to identify suitable process variables and reagents for the experimental section of the project. Particular emphasis was placed on the literature pertaining to anthracite. An in-depth review was beyond the scope of the project, considering the voluminous literature and the many factors which interact and influence the performance of flotation and agglomeration.

The objective of flotation is the preferential adherence of coal particles to air bubbles rising through the slurry. A fundamental requirement is that the coal adhere to the air bubbles. The coal laden bubbles rise to the surface of the flotation cell where they form a froth which can be skimmed off the surface. The ash particles remain in the aqueous phase and get transported out of the flotation cell along with the bulk of this phase. Most coals are hydrophobic (water fearing) and prefer an air-to-coal interface rather than a water-to-coal interface. The hydrophilic (water loving) ash particles prefer to remain wetted by the water and consequently have less tendency to adhere to the air bubbles. The degree of hydrophobicity of the coal often dictates how well it floats. Flotation practice often requires adjustment of both chemical and physical parameters to improve coal flotation.

Oil agglomeration also utilizes the hydrophobic nature of coal and the hydrophilic nature of ash to separate the two. In oil agglomeration a hydrocarbon bridging liquid or oil is added to the slurry and the oil preferentially adheres to the coal while the hydrophilic ash remains in the aqueous phase. The oil at the coal surface serves as a liquid bond that holds coal particles together to form larger agglomerated particles. These agglomerates are subsequently separated from the ash bearing aqueous phase by trapping the agglomerates on a screen whose openings are intermediate in size between the agglomerates and the ash particles.

Agglomeration flotation uses low levels of bridging liquid, typically less than 5%, and high shear mixing to produce micro-agglomerates. Flotation is then used to separate the micro-agglomerates from the liberated ash suspended in the aqueous phase. It is postulated that this process would be better than flotation

or agglomeration for difficult to float coals. The advantage over agglomeration is the use of low oil contents. The advantage over flotation is the benefit derived from higher collector rates (bridging liquid) and from the high shear agitation. The process is obviously subject to the variables that affect both flotation and agglomeration.

The performance of froth flotation and oil agglomeration is largely surface chemistry dependent. The basic difference in the surface chemistry of ash particles and coal constituents, when assisted by chemical reagents and physical parameters of operation, determines the separation of clean coal from rejects. Following is a summary of the literature review carried out on flotation and agglomeration for this research contract. Appendix 2 provides the detailed literature review and the references used in this literature survey.

2.1 Literature Review of Froth Flotation

Three major areas were covered in the literature review of froth flotation: coal properties, chemical reagents, and major physical parameters of froth flotation. Exhibit 1 displays the subjects reviewed in each area. Results of the literature review in each area are summarized as follows:

Exhibit 2	Summary of Review on Coal Properties
Exhibit 3	Summary of Review on Chemical Reagents
Exhibit 4	Summary of Review on Major Physical Parameters

Exhibit 1

Literature Review of Froth Flotation

Coal Properties	Chemical Reagents	Physical Parameters
Hydrophobicity	Frothers	Pulp Density
Floatability	Collectors	Impeller Speed
Oxidation	Promotors	Air Rate
Minerals	pH Modifiers	
Lithotypes		
Particle Size		

Exhibit 2

Summary of Review on Coal Properties

Subject	Effect on Flotation	General Conclusions from Literature	Remarks and Comments
Hydrophobicity	Positive	Increases as coal rank increases (due to reduction of hydrophilic groups -COOH and -OH)	------
Floatability (Contact angle)	------	Anthracite less hydrophobic than bituminous coals and semi-anthracite	Inconsistent with hydrophobicity but from actual measurement of contact angle
Oxidation	Negative	Decreases coal floatability (due to increases in hydrophilic groups)	Coal sample history related
Minerals	Negative	Decreases coal floatability due to clay slimes	Sample specific
Lithotypes	------	Vitrinite more floatable than other lithotypes (due to high aromatic content)	Consistent with hydrophobicity
Particle Size	Dependent on coal hydrophobicity particle density and fines content	0.3 mm top size for practical flotation of coal with high hydrophobicity Smaller top size for denser coals Preferential sorption of chemical reagents by fines may require additional staged dosages or size classification of feed	Separate size flotation investigated in this research contract

Exhibit 3

Summary of Review on Chemical Reagents

Function	Typical Dosage	Typical Chemicals	Effect on Flotation	General Conclusion from Literature	Remarks and Comments
Decrease bubble size and stabilize froth	0.1-0.3 kg/t	MIBC Pine Oil Cresylic Acid Glycols	Positive (required)	Increases product yield at increasing dosages Overdosing increases product ash	Newer frothers contain promotors Glycol based frothers more suitable for anthracite (private communications) Frother dosage based on pulp volume recommended by certain researchers
Increase hydrophobicity of coal surface	0.5-2.0 kg/t	Diesel Kerosene Fuel Oil Creosote	Positive (required)	Increases product yield at increasing dosages Overdosing increases product ash Lower viscosity collectors more effective	
Improve attachment of collector to coal	varies	Amines Esters Alkoxylated Fatty Acids	Positive (required for coal with poor floatability)	Increases coal floatability	Often formulated into frothers
Improve dispersion of collector	varies	Tensides Sulfosuccinates Ethoxylated alkyl phenols	Positive (required for coal with poor floatability)	Increases coal floatability	Often formulated into frothers
Alter electrical surface properties of coal	varies	NaOH HCl	Not usually significant in the pH range of commercial practice	Results vary	Neutral pH desirable for equipment and other processing considerations

Exhibit 4

Summary of Review of Major Physical Parameters

Parameters	Effect on Flotation	General Conclusion from Literature	Remarks and Comments
Pulp Density	Dependent on feed particle size	Typical range 5-15% Higher pulp density for coarse coals and lower pulp density for finer coal recommended	----
Impeller Speed	To be Optimized	High speed causes turbulence which could displace coal from air, low speed produces larger bubbles	----
Air Rate	To be Optimized	High rates cause turbulence and increase product ash; also cause larger bubbles. Low rates cause insufficient air and decrease product yield	----

2.2 Literature Review of Oil Agglomeration

As oil agglomeration is based on essentially the same principle as the flotation process, the summary of review presented in Exhibit 2 (coal properties) is judged to be adequate and can be extended in principle to the case of oil agglomeration.

Unlike the flotation process, there are no other chemical reagents used in the oil agglomeration process, except the bridging liquid. It is generally believed that the nature and quantity of the bridging liquid, the particle size of the feedstocks, and the agitation intensity of the process, are the major process variables in oil agglomeration. The summary of the literature review on the major parameters in oil agglomeration is provided in Exhibit 5.

Exhibit 5

Summary of Review of Oil Agglomeration

Parameters	Effect on Agglomeration	General Conclusion from Literature	Remarks and Comments
Bridging Liquid	Essential component in agglomeration process	Lighter and paraffin oils more selective than heavier and aromatic oils Quantity of oil depends on particle size	Staged agglomeration could use light oils for deashing and heavy oils for size enlargement
Particle Size	Significant	Finer particle sizes generally give lower ash product Higher consumption of oils for finer size particles	Oil agglomeration process usually applied to fine particles (<0.15 mm)
Agitation Intensity	Significant	High agitation improves oil dispersion and liberates minerals through attrition Higher intensity gives smaller agglomerates	
Residence Time	Dependent on coal hydrophobicity, bridging liquid viscosity, etc.	30 sec to 30 minutes reported for coal of good hydrophobicity to difficult coals with heavy oil Reduced residence time gives higher product ash, smaller agglomerates, and lower product yield	
Pulp Density	Improves particle contact	No effect on product ash when pulp density is less than 20% Increasing pulp density up to 20% increases product yield and agglomerate size	
pH	Varies	Generally considered as a minor parameter	

3.0 COAL SAMPLE AND CHARACTERIZATION

A sample of raw Mt. Klappan anthracite was taken from the property in 1986. The fines (0.6 mm x 0) were retained in Loring Laboratories Ltd. in Calgary in sealed drums. This sample was riffled and split into subsamples at the Coal Research Centre at Devon. The sample was subjected to various analyses, maceral composition determination, size analysis and washability study.

3.1 Analysis

Proximate, ultimate analyses and calorific value of the head sample were determined by Loring Laboratories Ltd. in Calgary. Ash content of the raw coal is approximately 20%. The carbonaceous portion of this sample is mainly carbon (70.82%). Both the hydrogen content (1.90%) and the oxygen content are low (4.50%). As a result, the raw coal has a relatively high calorific value (23.38 MJ/kg) at the 20% ash level.

Analytical data is presented in Table 1.

3.2 Maceral Composition

The maceral composition and the maximum reflectance were determined by David E. Pearson and Associates Ltd. in Victoria, B.C. One thousand counts were used in these determinations.

Major macerals in the sample are vitrinite (60.8%) and inert semifusinite (25.0%). Mean maximum reflectance is 4.25 and certain oxidized grains were observed. Oxidized coals give reduced reflectance and reflectance less than 2.5% was observed in the reflectogram. Due to the great difficulty in obtaining a 100% fresh coal from the Mt. Klappan property, this sample was used in the study despite the fact that slight oxidation of the sample was detected. (Estimated less than 4%.)

Data of maceral analysis is presented in Table 2.

3.3 Size Consist

The raw coal was screened to obtain a detailed size consist of the sample. Distribution of the 0.6 x 0.15 mm and 0.15 mm x 0 fractions are approximately 57% and 38%, respectively. Each size was also analyzed for ash content. The data is shown in Table 3.

It is observed that ash content increases sharply as particle size decreases. The 0.045 mm x 0 size fraction has an ash content of 48.1%.

3.4 Washability Data

The 0.6 x 0.15 mm and 0.15 x 0.045 mm size fractions were characterized for washability. These two size fractions combined represent approximately 75% of the raw sample.

The washability data of Table 4 indicates that for the 0.6 x 0.15 mm size fraction a clean coal at 6.67% ash content can be recovered theoretically at a yield of 93.2%. At the same cut point of 2.0 specific gravity, a clean coal of 7.36% ash and 82.6% recovery can be expected from the 0.15 x 0.045 mm size fraction.

4.0 EXPERIMENTAL AND DATA PRESENTATION

4.1 Reagents

The following information was obtained regarding the various reagents and bridging liquids used in the experimental program.

- Methyl isobutyl carbinol. Standard commercial grade reagent was used.
- Aerofroth 88. American Cyanamid product.
- Shur-coal 2057. Sherex Chemical Company product. Mixture of C_4-C_8 aliphatic alcohols.
- Shur-coal 168. Sherex Chemical Company product. Mixture of 85% frother: 15% promotor.
- Shur-coal 164. Sherex Chemical Company product. Mixture of 50% frother: 50% promotor.
- Shur-coal EPSC 137-64-4. Sherex Chemical Company product. Experimental product recommended by manufacturer for anthracite flotation. Diol Propoxylate glycol frother.
- Diesel. Commercial grade.
- Kerosene. Commercial grade.
- Bunker C. Husky Oil product, Lloydminster, Alberta.
- Heavy Oil. Husky Oil product, Lloydminster, Alberta. 22% asphalt content.
- Coal Tar. Stelco Inc. No. 1 By-Products Plant.

4.2 Flotation Tests

A Wemco laboratory flotation machine with a four litre glass cell was used for all flotation tests. A hand paddle was constructed to allow froth removal to be done at constant depth for all tests. Paddle depth was 1.0 cm below the cell's discharge level. This depth was also the liquid level at the beginning of each test. Four concentrates were collected for each froth flotation test.

For the most part, flotation tests were done using the following standard conditions. All tests were done by the same laboratory technologist to minimize operator error. The standard procedure developed for the flotation tests is detailed in Appendix 3.

The standard conditions used are as follows:

Variable	Standard
Coal size consist, mm	0.6 x 0
Pulp density, %	5
Water level	Decreasing
pH	7.5
Conditioning time, min	4
Collector	Diesel
Frother	MIBC
Impeller speed, rpm	1200
Air rate, L/hr	225

4.3 Agglomeration Tests

A Waring Commercial Blendor with 1 litre glass container was used as the agglomerating vessel. The blender had two speed settings.

For the most part, agglomeration tests were done using the standard conditions listed below. All tests were done by the same person following a standard procedure to improve reproducibility. Only a single concentrate was collected in the agglomeration tests. The standard procedure used is presented in Appendix 3.

The standard conditions used were:

Variable	Standard
Coal size consist, mm	0.15 x 0
Concentrate screen opening, mm	0.15
Pulp density, %	5
Water level	Constant
pH	7.5
Collector	Diesel
Collector dosage, kg/t	160
Agitation Sequence	30 sec low, 60 sec high, 90 sec low shear
Agitation Speeds, rpm	low shear: 12,000 high shear: 15,000

In the standard agglomeration tests the concentrate was separated from the tailings and then both fractions were analysed. In a number of tests the concentrate was returned to the agglomerating vessel, fresh water was added, and the concentrate was re-agglomerated at the same conditions as the first stage: 30 seconds low shear, 60 seconds high shear, and 90 seconds low shear. For some of these tests additional collector was added at the beginning of the re-agglomeration stage.

The concentrate from the re-agglomeration stage became the final concentrate. The tailings from each agglomeration stage were analysed separately.

4.4 Agglomeration Flotation

The agglomeration flotation tests were carried out in the agglomerating vessel with moderate levels of collector to form "micro-agglomerates." These micro-agglomerates were then separated from the tailings using flotation in the Wemco flotation cell. One single froth product was collected in this series of experiments. The standard procedure used is described in Appendix 3.

4.5 Determination of Ash Content of Agglomerate Concentrate

In analysing the agglomeration concentrates and tailings the first step was to dry each at 110°C. The dried fractions were then sub-sampled to obtain the analytical samples for ash content determination. For tests in which diesel, kerosene, or varsol were used as the bridging liquid, it was assumed that the 110°C drying temperature was sufficient to drive off the bridging liquids because of their low boiling points. Thus, the ash content determined was the ash content of the concentrates and tailings on a dry and bridging liquid free basis.

For bunker C, heavy oil and coal tar, the 110°C drying temperature was not sufficient to drive off all of the bridging liquid. Thus, the ash contents determined were on a dry basis; but including the bridging liquid. The quantity of bridging liquid remaining was a function of the originai dosage used as well as the length of drying time at 110°C. Proper evaluation of the results required that the analytical data be converted to a bridging liquid free basis.

For the purposes of this study it was assumed that the bridging liquid distributed itself in the concentrate and tailings in proportion to the carbon distribution of the concentrate and tailings. Based on this distribution, proportional weights were mathematically subtracted from the concentrate and tailings. An example illustrating the calculation of the actual ash content of agglomerates is shown in Appendix 3.

4.6 Data Presentation

The results of this research contract are presented in terms of product yield and ash content. For the most part, the results reported in the text are the average results of duplicate experiments. A complete list of all the experiments for the research contract is tabulated in Appendix 4. The efficiencies of the processes are reported in organic efficiency if possible, carbon recovery, and heat recovery. The definitions of these terms are described below:

Organic Efficiency

Ratio of actual yield to theoretical yield at the same ash level. Theoretical yield was determined from washability data.

i.e.	Product Yield	=		=	70%
	Ash % of Product	=		=	7%
	Theoretical Yield at 7% Ash	=		=	80%
	Organic Efficiency	=	70/80 x 100	=	87.5%

Carbon Recovery

Ratio of carbon recovery to total carbon content.

i.e.	Product Yield	=		=	70%
	Ash % of Product	=		=	7%
	Ash % of Feed	=		=	30%
	Carbon Recovery	=	$\frac{70 \times (100 - 7)}{(100 - 30)}$		
		=	93%		

Heat Recovery

Ratio of heat content in the product to the heat content in the feedstock.

i.e.	Product Yield	=		=	70%
	Heating Value of Product	=		=	30.12 MJ/kg
	Heating Value of Feedstock	=		=	23.01 MJ/kg
	Heat Recovery	=	$\frac{70 \times 30.12}{23.01}$		
		=	91.6%		

5.0 FROTH FLOTATION

5.1 General

The standard conditions and procedures established in Section 4 and Appendix 3 were closely followed in the froth flotation experiments. Froth was collected from the cell at a constant depth to ensure that there was no bias in sampling. Duplicate runs were conducted for most operating conditions and four concentrates (C1 to C4) were collected in each experiment. All the concentrates and tailings (T) were dried, weighed and analysed for weight and ash content.

The froth flotation experiments were performed at either decreasing liquid level or constant liquid level in the flotation cell. To maintain a constant liquid level in the froth cell, water was injected into the cell at a rate established from the water collected in the concentrates during the decreasing level experiments.

The complete list of the froth flotation experiments is attached in Appendix 4. The results reported in the following tables are, for the most part, the averages of duplicate tests. The test numbers refer to the data tabulated in Appendix 4. For example, Test 6 is the average of duplicate tests 6A and 6B of Appendix 4. Note that the basecase (Test 7) is the average of six tests, 7A - 7F. The results of these experiments are discussed in the following sections.

5.2 Process Variables

The effects of process variables on flotation of anthracite fines were evaluated using MIBC (Methyl isobutyl carbinol) frother at 0.3 kg/t and diesel collector at 1.0 kg/t as the basecase. The process variables and the range/scope of the variables are listed below:

VARIABLE	RANGE/SCOPE
Conditioning Time	0, 2, 4, 6 minutes
pH of Pulp	5, 7, 9
Agitation Intensity	900, 1,200, 1,500 rpm

VARIABLE	RANGE/SCOPE
Air Addition Rate	225, 340 litre/hour
Pulp Density	5, 10, 15 wt%
Frother	MIBC, Aerofroth 88,
	Shur-coal 164, 168, 2057, EPSC
Collector	Diesel, Kerosene, Varsol
Particle Size	0.6 x 0.15 mm
	0.15 mm x 0
	0.6 mm x 0

5.3 Results of Process Variables Evaluation

5.3.1 Effect of Conditioning Time

The effect of conditioning time on flotation of anthracite fines was evaluated at 0, 2, 4 and 6 minute levels. The experiments were carried out in decreasing liquid level configuration in the froth cell. The data from these experiments is shown in Table 5.

The results of this evaluation show that conditioning time has no significant effect on product yield, product ash content, and carbon recovery, in either the incremental froths or the final concentrate (the 180 s froth). Consequently a constant conditioning time of 4 minutes was used in all subsequent flotation experiments.

5.3.2 Effect of pH

The effect of pH was assessed at the pH levels of 5, 7.5 and 9, ranging from weak acidic to weak alkaline. Decreasing liquid level configuration in the froth cell was used in the experiments. All the data is presented in Table 6.

The results of this assessment show that weak acidic medium (pH 5) produced the highest yield and carbon recovery as well as the lowest product ash. The weak basic medium (pH 9) reduced the yield by about 25% with higher ash content. Neutral medium gave similar yield as the weak acidic medium and

essentially the same product ash. Neutral medium is obviously preferred in flotation.

Note that despite the initial pH, the final pH was basic. The natural pH of the system seems to be about 8.4. Tap water with a natural pH of about 7.5 was used in all experiments, including those for which the pH was adjusted to 5 and 9.

5.3.3 Effect of Agitation Intensity and Air Rate

The effects of agitation intensity (900, 1,200, 1,500 rpm) and air addition rate (225, 340 litre/hour) were studied using decreasing liquid level at the base dosages of MIBC frother and diesel collector. The results are shown in Table 7.

The experimental data indicate that product yield, product ash content and carbon recovery increased when agitation intensity increased. The increased ash content is believed to be caused by the effect of "throwing" ash particles into the froth at high agitation intensity. At low air addition rate, the yields of the froths were similar at different agitation intensities; but at high air addition rate, lower agitation intensity (900 rpm) was not sufficient to generate an acceptable recovery.

The results of the experiments conducted at the same level of agitation intensity (1,200 rpm) but at different air addition rate (Tests 7 and 27) show that product yield and carbon recovery were similar but the ash content increased as air rate increased. This appears to be caused by the increase in liquid level in the froth cell as air replaced liquid. The liquid level in the froth cell was raised substantially at high air rate which pushed ash particles to report to the froth. The total quantity of water collected in the froth for the experiment at 340 l/hr air rate was approximately 55% more than was collected at 225 l/hr air rate.

5.3.4 Effect of Pulp Density

The effect of pulp density was studied in experiments with decreasing and constant liquid levels in the flotation cell. Pulp densities of 5, 10 and 15 wt% were evaluated.

The results of the experiments done with decreasing liquid level in the flotation cell are presented in Table 8. The data suggests there is no significant effect of pulp density. There does appear to be an optimum at 10% pulp density since this condition gave the highest product yield and carbon recovery at the lowest product ash.

It was felt that with the decreasing liquid condition the liquid level dropped proportionately more for the high pulp density than for the low pulp density. Thus, the effect of pulp density was also investigated under constant liquid level conditions. Table 9 presents the data of these experiments. Table 9 confirms that decreasing liquid level affects high pulp density more than low pulp density. At high pulp density and constant liquid level, product yield, ash, and carbon recovery all increased to a greater degree relative to decreasing liquid level.

The effects of increasing pulp density from 5% to 15% (Test 29 versus Test 32) at constant liquid level are increased product yield and ash, and carbon recovery.

5.3.5 Effect of Frother

The effect of frother types and frother dosage were evaluated in this program. MIBC was used as the base reagent and the performances of other frothers (Aerofroth 88, Shur-coal 164, 168, 2057 and EPSC) were compared with the base case.

Table 10 shows the initial screening of MIBC frother without collector. At a dosage range of 0.1 to 0.3 kg/t, the data clearly showed that MIBC without collector was not acceptable. At a dosage of 0.3 kg/t, only 6.8% yield was obtained at an ash content of 18.0%. The ash content of the raw coal was approximately 21%. These results suggest that Mt. Klappan anthracite has no natural floatability; however, the mild oxidation detected in the petrographic analysis could be partially responsible.

Table 11 shows that significant improvement in flotation was achieved by adding diesel collector to MIBC frother. At 1.0 kg/t of diesel addition a product of 37.0% yield and an ash content of 7.7% was obtained.

Table 12 presents the results for different frothers. 0.3 kg/t of frother and 1.0 kg/t of diesel collector were used in this series of experiments. While the frother "Shur-coal 2057" gave inferior results than the base case, all the other Shur-coal products (164, 168 and EPSC) gave significant improvement over MIBC. The "Shur-coal EPSC," in particular, produced a visually superior froth which persisted throughout the test. It should be noted that the EPSC was a pure frother whereas the 164 and 168 contained promoters. For this reason the EPSC was used in the optimization tests even though the 168 performed marginally better. A 63.5% yield with an ash content of 8.4% and a carbon recovery of 73.9% were obtained with Shur-coal EPSC frother. Aerofroth 88 was ranked intermediate between the successful Shur-coal products and the base case.

The performance of all frothers is shown in Figure 1.

5.3.6 Effect of Collector

The effect of collector types and collector dosage were studied using experiments with decreasing liquid level. Three collectors were studied in this program: diesel, kerosene, and varsol. Varsol was selected in order to compare it to the oil agglomeration experiments, since the literature idenitified varsol (also known as Stoddard Solvent) as a commonly used bridging liquid in laboratory testing.

The effect of collector types at the dosage level of 1.0 kg/t and using MIBC frother at 0.3 kg/t is summarized in Table 13. The results show that diesel and kerosene are equivalent collectors for the flotation of Mt. Klappan anthracite fines. Varsol showed poor performance in this study. The performance of all collectors is shown graphically in Figure 2.

The effects of diesel dosage on flotation are presented in Table 14. The results show that as the diesel dosage increases the yield consistently increases

while product ash goes through a minimum. While the upper range of diesel dosage may not be practical in commercial operation (5.0 kg/t), the data suggest that a higher dosage of diesel is effective in beneficiating Mt. Klappan anthracite. The requirement of higher dosage of diesel is also related to the particle size effect as described in the following section. Froth yield in relation to diesel dosage is plotted in Figure 3.

5.3.7 Effect of Particle Size and Split Flotation

The effect of particle size on flotation was evaluated using 0.6 x 0.15 mm, 0.15 mm x 0 size fractions, and the raw coal at 0.6 mm x 0. The results of flotation using the full size consist were compared with split flotation of size fractions.

Table 15 compares the results of product yield and ash content for the two size fractions and the raw coal. The reconstituted data from the two size fractions is also shown. At the dosage of 0.3 kg/t MIBC frother and 1.0 kg/t diesel collector, the coarse size fraction (0.6 x 0.15 mm) gave a yield of 69.9% with an ash content of 6.7%. At the same dosage of frother and collector, the fine size fraction (0.15 mm x 0) only produced a froth of 37.7% yield with an ash content of 13.3%. The reconstituted data from these size fractions, when compared with the performance of the raw coal at 0.6 mm x 0, are only marginally higher in ash content (8.3% vs 7.9%), but significantly higher in product yield (57.5% vs 41.7%) and carbon recovery (67.1% vs 48.6%).

These results suggest that the bulk of the collector was consumed by the much larger surface area of the fines in the raw coal. When the raw coal was split into size fractions, collector was available for the coarse size fraction, making the flotation of the coarse material more effective. Consequently, the performance of the split flotation was superior to flotation of the raw coal without size separation.

The effect of collector dosage on flotation of different feed size consists were further studied using a superior frother, the Shur-coal EPSC. 0.3 kg/t of frother and various dosages of diesel collector were studied. The results are presented in Table 16.

The results show that low collector dosage (F0.2 kg/t) is beneficial for the flotation of the coarse size fraction. High dosage of collector (5.0 kg/t) tends to agglomerate the already coarse coal particles and makes them more difficult to float. The fine size fraction, on the contrary, shows good performance at higher collector dosage (f2.3 kg/t).

When the reconstituted data from the split flotation are compared with flotation of the raw material, the following are revealed. As long as the optimum dosages of collector were met for the coarse and fine size fractions, split flotation was better than or similar to flotation of full size consist (Tests (37 + 39) and (41 + 39) vs Test 24; and Tests (37 + 40) and (41 + 40) vs Test 34). There were slight increases in ash content in the products due to the improved flotation kinetics. It should be noted that about 90% of the flotation was completed in the first 30 seconds in split flotation.

However, if the optimum collector dosages were not fulfilled for both the coarse and fine size fractions, flotation of full size consist gave better performance than flotation of split size fractions. This is shown by comparing Test (36 + 35) to Test 34 and is due to the fact that the dosage of collector used for the coarse size fraction was 5.0 kg/t (Test 36).

5.4 Flotation of Anthracite Fines

The results of the process variables evaluation suggest the following optimum laboratory conditions for flotation of Mt. Klappan anthracite fines. The product yield and quality at these optimum conditions are also shown in this section.

5.4.1 Optimum Conditions

The optimum conditions for laboratory flotation of Mt. Klappan anthracite fines are summarized below:

Frother:	Shur-coal EPSC	0.3 kg/t
Collector:	Diesel	
	For full size consist	
	of 0.6 mm x 0	1.0 kg/t
	For split size flotation	
	0.6 x 0.15 mm	0.2 kg/t
	0.15 mm x 0	2.3 kg/t
pH of Pulp	neutral	pH = 7
Conditioning Time		4 minutes
Agitation Intensity		1,200 rpm
Air Rate		225 litre/hour
Pulp Density		5%

5.4.2 Product Yield and Product Quality

Product yield at 180 seconds and the quality of the products from flotation of full size or split sizes are summarized below. It should be noted that split size flotation has improved flotation kinetics, as shown in Figure 4.

	0.6 x 0.15 mm		0.15 mm x 0		0.6 mm x 0	
	Yld %	Ash %	Yld %	Ash %	Yld %	Ash %
Froth at 30 sec	66.8	6.9	61.6	13.6	15.7	7.6
60 sec	72.5	7.2	65.3	14.2	26.8	7.2
90 sec	74.6	7.3	66.9	14.6	38.1	7.2
180 sec	76.8	7.4	68.7	15.1	63.5	8.3
Tailing	23.2	42.5	31.3	67.6	36.5	43.9
Organic Efficiency %	82.4*		---		---	
Carbon Recovery %	84.2		85.2		73.9	
Heat Recovery %	84.8		89.0		77.4	

*Estimated from washability data of 0.6 x 0.15 mm size fraction
At 2.00 specific gravity (93.3% yield at 6.7% ash).

6.0 OIL AGGLOMERATION

6.1 General

The procedures followed for the oil agglomeration tests are provided in Section 4 and Appendix 3.

The standard test conditions are provided in Section 4.3. For the most part the test program was devised to confirm or demonstrate the effects of the process variables or to optimize the beneficiation results (maximize carbon recovery and minimize product ash).

For the most part, the results reported in the following sections are the averages of duplicate tests and are on a dry and bridging liquid-free basis (see Appendix 3). Appendix 4 provides the data for the individual tests that make up the averages as well as the data on a bridging liquid-in basis.

6.2 Process Variables

The range/scope of the variables that were evaluated were:

VARIABLE	RANGE/SCOPE
Bridging liquid addition rate, kg/t	10 - 200
Bridging liquid type	Diesel, Bunker C, Varsol, Coal Tar, Heavy Oil
Feed size consist, mm	0.6 x 0, 0.15 x 0
pH	5, 7, 9
Agitation intensity, rpm	1,000, 15,000
Residence time, sec	30, 180
Pulp density, %	5, 10, 15
Concentrate washing/re-agglomeration	

6.3 Results of Process Variables Evaluation

6.3.1 Effect of Bridging Liquid Addition Rate

Table 17 and Figure 5 show the effect of bridging liquid addition rate on both concentrate yield and ash.

Concentrate ash decreases at first but then begins to increase. At the low diesel rates, 10 kg/t, flocs and/or micro-agglomerates are formed. They tend to blind the concentrate screen, thereby trapping water and its associated liberated ash. Also, many of the micro-agglomerates can and do pass through the screen, resulting in poor carbon recovery. As the diesel rate increases the flocs densify to form true agglomerates which are of increased size. This facilitates the separation on the concentrate screen of the agglomerates from the ash laden water. Concentrate ash begins to increase at high bridging liquid rates due to the increased recovery of the poorer quality coal particles. The data of Bunker C confirms the trends established with the diesel at the higher bridging liquid levels.

The results show that carbon recovery increases as diesel addition rate increases.

6.3.2 Effect of Bridging Liquid Type

Table 18 presents results using diesel, Bunker C, and varsol as bridging liquids. The data indicates that the three bridging liquids produce similar products although Bunker C is superior with respect to carbon recovery . The improved recovery is due to the larger and stronger agglomerates produced by the Bunker C.

The high shear agitation used in the agglomeration tests makes the use of oils such as Bunker C possible. Such high shear is required to effectively disperse more viscous oils such as Bunker C.

6.3.3 Effect of Agitation Intensity and Residence Time

Table 19 presents the data from the tests of agitation intensity and residence time. The tests used diesel oil which is readily dispersible. The high shear condition represents about 15,000 rpm and the low shear about 1,000 rpm. (Note that in all other tests the low shear was about 12,000 rpm.)

Table 19 indicates that high shear increases carbon recovery. The effect on concentrate ash was inconsistent.

With respect to the effect of increasing agitation time (residence time), there is a reduction in both concentrate yield and ash. Carbon recovery, however, remains about the same regardless of agitation time.

No doubt the use of diesel oil reduced the effects of agitation intensity and time. A more viscous oil, such as Bunker C, would not disperse as readily as diesel. Thus, one would predict that with viscous oils carbon recovery would decrease as agitation intensity and time decrease. It is more difficult to predict what the effect would be on concentrate ash.

When evaluating the effects of agitation intensity and time the bridging liquid addition rate must also be considered. At the high addition rates used in the experiments agitation becomes less critical because there is sufficient oil to contact and wet most of the coal particles. At low addition rates higher shear and longer times are required to increase the chances of contact between bridging liquid and coal particles. Also, the importance of agitation intensity and time would be inversely proportional to coal hydrophobicity.

6.3.4 Effect of pH

Table 20 presents the results of agglomeration tests done at three pH levels: 5, 7 and 9. HCl and NaOH were used as the pH modifiers. The pH values refer to the initial pH of the water used in the tests. Table 20 indicates that the

final pH is not directly proportional to the starting pH. For the other agglomeration tests done in this study the starting pH was typically 7.5 and the final pH was typically 7.6 to 8.3. Table 20 indicates that pH has no significant effect over the range tested.

6.3.5 Effect of Pulp Density

Table 21 indicates that the primary effect of increasing pulp density is to increase product ash, with a corresponding increase in product yield. Carbon recovery, however, remains constant.

Since the same screen surface area was used to recover the agglomerates, as pulp density increased screen loading increased, which resulted in less efficient separation/dewatering of the agglomerates and a consequential increase in the product yield and ash.

Table 22 compares the size distributions and ash contents of agglomerates produced from 5% and 15% pulp densities. The agglomerates produced from each pulp density were thoroughly wet screened (i.e. washed on vibrating sieves with a mild jet of fresh water) in order to eliminate the aforementioned effect of screen loading. The results of Table 22 suggest that 15% pulp density yields equivalent product to 5% pulp density.

The results of Table 22 also indicate that the normal concentrate recovery screening procedure traps many minus 0.15 mm agglomerates as well as ash, regardless of initial pulp density. As pulp density increases, the concentration of ash in the aqueous phase also increases. Thus, even at constant product moisture, the product ash would increase as pulp density increases; however, since product moisture increases due to less efficient dewatering, the result is an incremental increase in ash due to increasing pulp density.

By re-washing or re-agglomerating the concentrate it is possible to reduce the ash content of the concentrate. Table 23 shows that concentrate ash can be significantly reduced through this procedure. Table 23 also indicates that the improvement in product ash is due to a large extent to the removal of the ash

trapped in the water that remains with the concentrate. This can be inferred from the fact that simply washing the concentrate with a mild flow of clean water reduced the ash content almost as much as complete re-agglomeration of the concentrate.

6.3.6 Agglomeration of Coarse Coal

The results presented in sections 6.3.1 to 6.3.5 were solely for tests done with minus 0.15 mm feed. The agglomerates produced in these tests were recovered on a screen of 0.15 mm opening. The liberated ash particles could pass through the screen while coal particles that agglomerated to form plus 0.15 mm agglomerates remained on the screen. Thus, the screen used to trap the agglomerates should have openings equal to the top size of the feed or at least equal to the size of the coarsest ash particle.

Several preliminary tests were done with the full size consist feed, 0.6 mm x 0, using a 0.85 mm opening screen for agglomerate recovery. Table 24 indicates that only test no. 37 gave acceptable results. The results indicate that for the other tests much of the agglomerated coal was passing through the screen, as evidenced by the low tailings ash values and the poor carbon recovery.

A number of tests were done using the full size consist feed and the 0.15 mm opening screen for agglomerates recovery. A wide variety of conditions were tried, the objective being to maximize yield and carbon recovery and to minimize product ash. Table 25 presents the results of these tests. The results indicate that the objectives of high yield and carbon recovery at low product ash were met; however, some of the tests yielded products of ash contents that were better than theoretically possible.

The theoretical ash content of the product recovered on a 0.15 mm screen can be estimated from the characteristics of the feedstock. The 0.6 mm x 0 feedstock (21.3 % ash) consists of 64.8% plus 0.15 mm particles (14.2% ash) (see Table 26) and 35.2% minus 0.15 mm fines (34.4% ash). Theoretical recovery of fines, assuming total rejection of ash and complete agglomeration of coal, is therefore 23.1% (35.2% of (100 - 34.4)). In principle, all the plus 0.15 mm particles,

ash or carbonaceous material, should also be recovered on the product screen. The total recovery of product, therefore, is 87.9% (64.8% + 23.1%) with an average ash content of 10.5% ((64.8 x 14.2 + 23.1 x 0) ÷ (87.9)).

Table 26 indicates the reason for the better than theoretical results. The results show that the impellers in the agglomerating vessel grind the coarse particles and liberate ash. Thus, the high shear agitation used in the agglomeration process is partially responsible for the low ash products achievable. Based on the data of Table 26, the theoretical minimum product ash after one stage of agglomeration would be 6.0% and 4.8% after two stages of agglomeration, when the feed is the full size consist and a 0.15 mm opening screen is used to recover the agglomerates.

6.4 Optimization of Oil Agglomeration

The preceeding results indicate that diesel and Bunker C give similar results, that high levels of bridging liquid are required to maximize carbon recovery, and that some form of concentrate washing is required to minimize product ash. Three optimization tests were done, two with the full size consist (0.6mm x 0) and one with the fine fraction (0.15 mm x 0).

For each test the concentrate plus tailings were wet screened on 0.6, 0.3, and 0.15 mm opening screens. Diesel and Bunker C were used for the 0.6 mm x 0 feed. Bunker C was used for the 0.15 mm x 0 feed. The test results are presented in Table 27.

The results for the 0.6 mm x 0 feed with diesel bridging liquid indicate that the conditions used were not, in fact, optimum. Better results had been obtained previously, notably in Test No. 45 (Table 25). It seems that some of the diesel agglomerates broke down and passed through to the tailings, resulting in poor carbon recovery and low tailings ash.

The results with Bunker C were significantly better than those with diesel. A higher ash product was obtained with Bunker C (9.7% vs. 8.5%), but carbon recovery and yield were significantly greater (96.2% vs. 87.0% and 83.8%

vs. 69.6%, respectively). The size distributions of the Bunker C and diesel agglomerates indicate that Bunker C produces significantly larger and stronger agglomerates.

The results of the 0.6 mm x 0 optimized test done with Bunker C are comparable to the best results obtained in the evaluation of process variables (Table 25, Test No. 45). This latter test involved two-stage agglomeration for minimizing product ash, compared to the thorough wet screening used in the optimization test. Consequently, the product ash of the optimized test is greater, 9.7% vs. 8.6%, due to the fact that the two-stage agglomeration liberated ash due to the additional attrition occurring in the second stage.

The results obtained with the 0.15 mm x 0 feed were significantly better than any previous results, most of which had been obtained using diesel. The optimized results gave equivalent carbon yield at 50% lower product ash than previous diesel results (i.e., Table 17, Test No. 7). In comparison to previous Bunker C results the optimized product had 50% lower product ash but at about 7% lower carbon recovery (Table 17, Test No. 9). At equivalent carbon recovery, the optimized product had a 16% reduction in product ash (Table 23, Test No. 23).

The optimization tests indicate that to achieve high carbon recovery at low product ash, high levels of bridging liquid (i.e., 20%) are required. Furthermore, the bridging liquid must be capable of producing strong agglomerates that are able to withstand the concentrate washing that is required to remove trapped ash from the concentrate.

7.0 AGGLOMERATION FLOTATION

7.1 General

The preceeding section dealing with agglomeration showed that the screening method of recovering agglomerates is not effective at low levels of bridging liquid; however, in order to keep operating costs to a minimum it is desirable to use the least amount of bridging liquid possible. Since the bridging liquid in agglomeration is often the same liquid as the collector in flotation, it seems logical that flotation should offer an alternative to screening for recovering agglomerates.

This section presents the results of tests in which agglomerates were produced, the pulp transferred to the flotation cell, diluted to the desired pulp density, a frother added, and flotation used to produce a froth which was subsequently removed from the flotation cell by paddling. The experimental procedure is described in detail in Appendix 3.

7.2 Process Variables

The variables that were investigated were:

VARIABLE	RANGE/SCOPE
Bridging liquid type	Diesel, Bunker C
Bridging liquid addition rate, kg/t	1 - 20
Feed size consist, mm	0.6 x 0, 0.15 x 0

The results from the flotation and agglomeration tests were taken into consideration when doing the agglomeration flotation tests. Consequently, in the flotation stage pulp density was constant at 5% and the frother was Shur-coal EPSC added at a rate of 0.3 kg/t. In the agglomeration stage the pulp density was 30%, which was a significant departure from the maximum of 15% used in the agglomeration tests of Section 6. This was necessary in order to treat all of the coal required for 5% pulp density in flotation, approximately 150 g, in one batch in the Waring Blendor instead of two or more batches. Agglomeration residence time was increased to compensate for the higher pulp density.

7.3 Results of Process Variables Evaluation

7.3.1 Effect of Bridging Liquid Type

Table 28 presents the results of tests done using either diesel or Bunker C as the bridging liquid. The data suggests that there is no significant difference in performance between diesel and Bunker C.

The significance of Table 28 is that Bunker C can be used to give a high yield in flotation. The high shear used in the agglomeration stage makes this possible. Chemical emulsification would be required if Bunker C were to be used in a conventional flotation system.

7.3.2 Effect of Bridging Liquid Addition Rate

Table 29 indicates that increasing the bridging liquid addition rate beyond 5 kg/t has no significant effect on the agglomeration flotation process; however, there is a significant effect as bridging liquid addition rate increases from the 1.0 kg/t level to 5.0 kg/t. The major effect is an increase in yield and carbon recovery while product ash remains constant.

7.3.3 Effect of Feed Size Consist

Table 30 indicates that the relative performance of agglomeration flotation on the two size fractions was not affected by bridging liquid addition rate. The performance with the 0.15 mm x 0 feed would probably deteriorate faster than for the 0.6 mm x 0 feed as the bridging liquid rate decreased below 10 kg/t. Also, during the flotation stage it was noted that the froth was barren of solids about 45 seconds before the end of the 0.6 mm x 0 feed tests whereas there was a small quantity of coal left at the end of the 0.15 mm x 0 feed tests.

8.0 COMPARISON OF TEST METHODS

Table 31 compares results from flotation, agglomeration and agglomeration flotation tests done under similar conditions.

The data indicates that at low bridging liquid levels agglomeration flotation is superior to agglomeration. Agglomeration flotation gives similar product ash but at significantly higher carbon recovery. The low levels of bridging liquid are not sufficient to create agglomerates that are large enough to be trapped by the concentrate screen used in the agglomeration process.

Comparison of the flotation and agglomeration flotation results suggests that flotation is superior, particularly at very low collector/bridging liquid addition rates. At the higher collector/bridging liquid addition rates agglomeration flotation consistently gave higher product ash levels, although at higher product yield and carbon recovery.

The performance of oil agglomeration improves significantly if high dosages of bridging liquid are used. This makes the process uneconomic relative to flotation and agglomeration flotation. Economics aside, the results for oil agglomeration at high dosages of bridging liquid are similar to the results of flotation and agglomeration flotation unless either re-agglomeration or washing of the agglomerates is done.

9.0 CONCLUSIONS

Froth flotation and oil agglomeration experiments are carried out in a system influenced by a large number of process variables. The interactions between process parameters often complicate the effect and consequently the interpretation of certain variables. The following summarize the general conclusions that can be derived from the experimental program.

9.1 Froth Flotation

- Glycol based frothers (e.g., Shur-coal EPSC) and a number of proprietary frothers with promoters, perform differently from straight alcohol based frothers (e.g., MIBC, Shur-coal 2057). The presence of polyhydroxyl functional groups appears to have a positive impact on the flotation of anthracite fines.

- Diesel and kerosene are comparable in performance when used as collectors. Varsol performs poorly as a collector.

- Low collector dosage (F0.2 kg/t) is beneficial for the flotation of coarse particles (0.6 x 0.15 mm). Higher collector dosage (f2.3 kg/t) improves the flotation of the fines (0.15 mm x 0).

- If the optimum collector dosages are not fulfilled for the coarse and fine particles, flotation of full size consist gives better results than flotation of split size fractions.

- Increasing agitation intensity above the optimum tends to increase product yield and product ash by "throwing" particles into the froth. Increasing air rate above the optimum increases ash content of the froth.

- At the levels tested, the effects of conditioning time and pulp density were not significant in flotation of anthracite fines.

- A neutral to weakly acidic pH is desirable. Alkaline medium is undesirable.

- Under the optimum conditions established in this study and using Shur-coal EPSC as a frother, a 79.2% recovery of a clean coal at 10.2% ash was observed for a feed of 0.6 mm x 0 size consist (21.3% ash). A 68.7% recovery of a clean coal at 15.1% ash was achieved for the 0.15 mm x 0 size consist feedstock (33.0% ash).

9.2 Oil Agglomeration

- Bunker C produces stronger and larger agglomerates than diesel. Size analysis of agglomerates produced from a 0.6 mm x 0 feedstock show that 40.3% of the agglomerates from Bunker C are larger than 0.6 mm, while only 5.0% of the agglomerates from diesel are larger than 0.6 mm.

- As bridging liquid dosages increase, carbon recovery of the agglomerates increases. Ash content of the agglomerates increases at low dosage of bridging liquid due to the formation of flocs. Ash content decreases at intermediate dosage level and then increases again at high dosages due to the recovery of poor quality coal.

- Rewashing the agglomerates can significantly reduce the ash content of the product. The ash content of the agglomerates produced with Bunker C was reduced from 14.6% to 10.9%, with only 5.4% loss in yield.

- Ash liberation from coarse particles was observed under high shear mixing. Ash content of the plus 0.15 mm fraction was reduced from 14.2% to 8.7% due to ash liberation.

- The effect observed for pulp density is a combination of effects from pulp density and screen loading. This combined effect observed for higher pulp density is higher product yield and higher ash content.

- Over the pH range of 5 to 9, the effect of pH is not significant in agglomeration of Mt. Klappan anthracite fines.

- Under the optimum conditions and using Bunker C, a clean coal yield of 83.8% at 9.7% ash was produced from a feedstock of 0.6 x 0 mm size consist (21.3% ash). When the 0.15 mm x 0 feedstock (33.0% ash) was processed, a clean coal recovery of 63.0% at 8.2% ash was obtained.

9.3 Agglomeration Flotation

- Flotation is a feasible method for separating microagglomerates from tailings. Bridging liquid dosage can be significantly reduced (from 160 kg/t to 5-10 kg/t).

- Under the optimum condition established, a clean coal of 84.7% recovery at an ash content of 11.9% was achieved for the 0.6 mm x 0 (21.3% ash). When a feedstock of 0.15 mm x 0 size fraction (33.0% ash) is processed, a recovery of 76.0% clean coal at an ash content of 17.8% was realized.

- The best results obtained by these techniques are shown in Figures 6 and 7 for the 0.6 x 0 mm and 0.15 x 0 mm size fractions, respectively.

10.0 RECOMMENDATIONS

1. Re-cleaning of the froth concentrate from flotation and from agglomeration flotation was not investigated in this project. This option should be investigated in order to reduce product ash below the levels obtained in this study.

2. The full size consist feedstock used in this study contained about 64% plus 0.15 mm particles. The results obtained in this study should be compared to gravimetric cleaning of the 0.6 x 0.15 mm fraction.

Table 1

Analysis of Mt. Klappan Anthracite Fines (0.6 mm x 0)

		As-Received	Dry, Ash-Free
Proximate Analysis			
	Residual Moisture %	1.58	--
	Volatile Matter %	8.18	10.43
	Ash %	19.98	--
	Fixed Carbon %	70.26	89.57
Ultimate Analysis			
	Residual Moisture %	1.58	--
	Ash %	19.98	--
	Carbon %	70.82	90.28
	Hydrogen %	1.90	2.42
	Nitrogen %	0.80	1.02
	Sulfur %	0.42	0.54
	Oxygen (by difference) %	4.50	5.74
	Calorific Value (MJ/kg)	23.38	29.81

Table 2

Maceral Composition of Mt. Klappan Anthracite Fines (0.6 mm x 0)

Petrographic Indices

Mean Maximum Reflectance	%	4.25

Maceral Composition

Vitrinite	%	60.8
Macrinite	%	0.8
Inert Semifusinite	%	25.0
Fusinite	%	2.1
Inertodetrinite	%	0.4
Mineral Matter	%	10.9

Table 3

Size Consist of Mt. Klappan Anthracite Fines

Size Fraction mm	Instantaneous Wt %	Instantaneous Ash %	Cumulative Wt %	Cumulative Ash %
+0.6	4.6	11.3	4.6	11.3
0.6 x 0.3	30.8	11.5	35.5	11.5
0.3 x 0.15	26.2	16.1	61.6	13.4
0.15 x 0.075	12.4	20.3	74.0	14.6
0.075 x 0.045	5.8	26.4	79.9	15.5
-0.045	20.1	48.1	100.0	22.0

Table 4

Washability of Mt. Klappan Anthracite Fines

	0.6 x 0.15 mm				0.15 x 0.045 mm			
	Instantaneous		Cumulative		Instantaneous		Cumulative	
	Wt %	Ash %	Wt %	Ash %	Wt %	Ash %	Wt %	Ash %
Float 1.40	6.52	0.70	6.52	0.70	0.00	0.00	0.00	0.00
1.40 x 1.45	19.59	1.48	26.11	1.28	2.31	0.92	2.31	0.92
1.45 x 1.50	43.51	3.88	69.62	2.91	41.69	2.02	44.00	1.97
1.50 x 1.55	9.33	10.25	78.95	3.77	12.32	5.00	56.32	2.63
1.55 x 1.60	5.53	14.49	84.48	4.48	6.75	9.33	63.07	3.35
1.60 x 1.70	1.39	19.00	85.87	4.71	3.81	10.47	66.88	3.75
1.70 x 1.80	4.02	20.77	89.89	5.43	11.13	16.65	78.01	5.59
1.80 x 2.00	3.36	39.76	93.25	6.67	4.55	37.56	82.56	7.36
Sink 2.00	6.75	85.85	100.00	12.01	17.44	88.46	100.00	21.50

Table 5

Effect of Conditioning Time

Standard Conditions: 0.3 kg/t MIBC, 1.0 kg/t Diesel

Test Conditions		Cumulative Concentrate Analyses								Tails		Feed	Carbon
Test No.	Conditioning Time (minutes)	30 Sec % YLD	30 Sec % ASH	60 Sec % YLD	60 Sec % ASH	90 Sec % YLD	90 Sec % ASH	180 Sec % YLD	180 Sec % ASH	% YLD	% ASH	Reconst % ASH	Recovery %
16	0	14.6	6.8	21.1	6.6	28.2	6.6	36.6	6.9	63.4	29.6	21.3	43.4
17	2	14.0	6.9	22.5	6.9	27.8	7.0	34.7	7.4	65.3	28.9	21.4	40.9
7	4	17.3	7.2	24.9	7.1	30.1	7.2	37.0	7.7	63.0	29.4	21.4	43.4
18	6	14.8	7.2	21.7	7.3	25.4	7.3	31.8	7.7	67.2	27.9	21.4	37.4

Table 6
Effect of pH of Pulp

Standard Conditions: 0.3 kg/t MIBC, 1.0 kg/t Diesel

Test No.	Test Conditions pH		Cumulative Concentrate Analyses								Tails		Feed Reconst	Carbon Recovery
			30 Sec		60 Sec		90 Sec		180 Sec					
	Initial	Final	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% ASH	%
14	5.0	7.7	18.9	7.6	27.5	7.3	33.6	7.3	40.9	7.5	59.1	30.4	21.0	47.9
7	7.5	8.4	17.3	7.2	24.9	7.1	30.1	7.2	37.0	7.7	63.0	29.4	21.3	43.4
15	9.0	8.5	12.7	8.9	18.9	8.4	23.3	8.2	29.9	8.3	70.1	27.2	21.5	35.0

Table 7

Effect of Agitation Intensity and of Air Rate

Standard Conditions: 0.3 kg/t MIBC, 1.0 kg/t Diesel

Test No.	Test Conditions		Cumulative Concentrate Analyses								Tails		Feed Reconst	Carbon Recovery
			30 Sec		60 Sec		90 Sec		180 Sec					
	Impeller rpm	Air Rate l/h	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% ASH	%
26	900	340	8.6	5.2	11.9	5.8	13.1	6.2	15.1	7.1	84.9	24.4	21.8	18.0
27	1200	340	20.1	7.8	27.6	7.9	32.1	8.0	36.2	8.5	63.8	29.3	21.8	42.3
7	1200	225	17.3	7.2	24.9	7.1	30.1	7.2	37.0	7.7	63.0	29.4	21.3	43.4
28	1500	225	22.1	8.3	29.2	9.7	32.0	10.2	38.9	11.6	61.1	27.5	21.4	43.7

Table 8

Effect of Pulp Density (Decreasing Liquid Level)

Standard Conditions: 0.3 kg/t MIBC, 1.0 kg/t Diesel

Test No.	Test Conditions Pulp Density (wt%)	Cumulative Concentrate Analyses								Tails		Feed Reconst % ASH	Carbon Recovery %
		30 Sec		60 Sec		90 Sec		180 Sec					
		% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH		
7	5	17.3	7.2	24.9	7.1	30.1	7.2	37.0	7.7	63.0	29.4	21.3	43.4
19	10	22.1	7.1	29.5	7.2	33.8	7.3	40.3	7.5	59.7	30.1	21.0	47.2
20	15	26.1	7.5	30.4	7.6	33.5	7.7	38.3	7.9	61.7	29.1	20.9	44.6

Table 9

Effect of Pulp Density (Constant Liquid Level)

Standard Conditions: 0.3 kg/t MIBC, 1.0 kg/t Diesel

Test No.	Test Conditions A Tests: 5% Pulp D B Tests: 15% Pulp D	Cumulative Concentrate Analyses								Tails		Feed Reconst	Carbon Recovery
		30 Sec		60 Sec		90 Sec		180 Sec					
		% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% ASH	%
7	A, Decreasing Level	17.3	7.2	24.9	7.1	30.1	7.2	37.0	7.7	63.0	29.4	21.3	43.4
29	A, Constant Level	17.2	6.8	27.6	6.9	34.3	7.1	41.7	7.9	58.3	30.4	21.0	48.6
20	B, Decreasing Level	26.1	7.5	30.4	7.6	33.5	7.7	38.3	7.9	61.7	29.1	20.9	44.6
32	B, Constant Level	28.8	7.7	36.6	7.9	41.1	8.2	46.8	9.6	53.2	31.5	21.3	53.7

Table 10

Effect of MIBC Addition Rate

Standard Conditions: No Collector

Test No.	Test Conditions MIBC Dosage (kg/t)	Cumulative Concentrate Analyses								Tails		Feed Reconst	Carbon Recovery
		30 Sec		60 Sec		90 Sec		180 Sec					
		% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% ASH	%
1	0.0	0.6	20.3	1.1	21.0	1.6	21.1	2.6	21.3	97.4	20.6	20.6	2.6
2	0.1	0.5	20.4	0.8	20.8	1.1	20.9	1.9	21.3	98.1	20.2	20.2	1.8
3	0.2	0.7	19.8	1.1	20.5	1.6	20.8	2.6	21.0	97.4	22.3	22.2	2.6
4	0.3	2.6	18.4	3.6	18.1	4.7	18.1	6.8	17.9	93.2	21.4	21.2	7.0

Table 11

Effect of Diesel Addition Rate On MIBC Frother

Standard Conditions: 0.3 kg/t MIBC

Test No.	Test Conditions Diesel Dosage (kg/t)	Cumulative Concentrate Analyses								Tails		Feed Reconst	Carbon Recovery
		30 Sec		60 Sec		90 Sec		180 Sec					
		% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% ASH	%
5	0.25	6.7	10.5	9.4	10.6	10.9	10.9	13.1	11.6	86.9	23.1	21.6	14.7
6	0.50	11.9	8.0	16.2	8.1	18.8	8.4	22.0	9.0	78.0	24.6	21.1	25.3
7	1.00	17.3	7.2	24.9	7.1	30.1	7.2	37.0	7.7	63.0	29.4	21.3	43.4

Table 12

Results Using Different Frothers

Standard Conditions: 0.3 kg/t Frother, 1.0 kg/t Diesel

Test No.	Test Conditions Frother	Cumulative Concentrate Analyses								Tails		Feed Reconst	Carbon Recovery
		30 Sec		60 Sec		90 Sec		180 Sec					
		% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% ASH	%
7	MIBC	17.3	7.2	24.9	7.1	30.1	7.2	37.0	7.7	63.0	29.4	21.3	43.4
21	SHUR-COAL 168	20.0	7.2	35.2	7.1	46.9	7.3	66.4	8.3	33.6	47.4	21.4	77.4
22	SHUR-COAL 164	20.1	7.7	33.1	7.3	43.8	7.4	64.8	8.2	35.2	44.8	21.1	75.4
23	SHUR-COAL 2057	11.4	9.1	18.3	7.5	23.0	7.5	28.5	7.5	71.5	26.8	21.3	33.4
24	SHUR-COAL EPSC	15.7	7.6	26.8	7.2	38.1	7.2	63.5	8.3	36.5	43.9	21.3	73.9
25	AEROFROTH 88	15.1	7.4	23.7	7.0	31.1	7.0	43.7	7.3	56.3	31.7	21.0	51.3

Table 13
Effect of Collector Type

Standard Conditions: 0.3 kg/t MIBC, 1.0 kg/t Collector

Test No.	Test Conditions Collector	Cumulative Concentrate Analyses								Tails		Feed Reconst	Carbon Recovery
		30 Sec		60 Sec		90 Sec		180 Sec					
		% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% ASH	%
7	Diesel	17.3	7.2	24.9	7.1	30.1	7.2	37.0	7.7	63.0	29.4	21.3	43.4
11	Kerosene	25.7	7.1	32.1	7.1	34.6	7.2	36.4	7.7	63.6	29.0	21.2	42.7
12	Varsol	7.6	17.1	9.4	17.3	10.7	17.2	13.4	16.7	86.6	22.4	21.7	14.3

Table 14

Effect of Diesel Addition Rate

Standard Conditions: 0.3 kg/t MIBC,

Test No.	Test Conditions Diesel Dosage (kg/t)	Cumulative Concentrate Analyses								Tails		Feed Reconst	Carbon Recovery
		30 Sec		60 Sec		90 Sec		180 Sec					
		% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% YLD	% ASH	% ASH	%
5	0.25	6.7	10.5	9.4	10.6	10.9	10.9	13.1	11.6	86.9	23.1	21.6	14.7
6	0.50	11.9	8.0	16.2	8.1	18.8	8.4	22.0	9.0	78.0	24.6	21.1	25.3
7	1.00	17.3	7.2	24.9	7.1	30.1	7.2	37.0	7.7	63.0	29.4	21.3	43.4
8	1.75	24.2	6.6	36.2	6.8	42.5	6.9	51.9	7.3	48.1	36.0	21.1	60.9
9	2.50	40.8	7.2	50.0	7.3	55.4	7.5	59.5	7.9	40.5	41.1	21.4	69.6
10	5.00	49.7	7.7	62.0	8.0	67.3	8.2	71.1	8.7	28.0	52.7	21.4	82.6

Table 15

Effect of Size Consist

Standard Conditions: 0.3 kg/t MIBC, 1.0 kg/t Diesel, Constant Level

Test No.	Test Conditions Size Fraction mm	Cumulative Concentrate Analyses 30 Sec % YLD	30 Sec % ASH	60 Sec % YLD	60 Sec % ASH	90 Sec % YLD	90 Sec % ASH	180 Sec % YLD	180 Sec % ASH	Tails % YLD	Tails % ASH	Feed Reconst % ASH	Carbon Recovery %
30	0.6 x 0.15	8.0	4.0	22.4	4.3	36.7	4.8	69.9	6.7	30.1	35.2	15.2	76.9
31	0.15 x 0	23.8	11.2	30.5	11.6	33.5	12.0	37.7	13.3	62.3	42.1	31.2	47.5
29	0.6 x 0	17.2	6.8	27.6	6.9	34.3	7.1	41.7	7.9	58.3	30.4	21.0	48.6
	Reconstituted 0.6 x 0 (0.6 x 0.15 + 0.15 x 0)												
30 & 31	reconst. 0.6 x 0	14.1	8.7	25.5	7.6	35.5	7.4	57.5	8.3	42.5	39.1	21.4	67.1

Table 16

Optimization Tests Using Separate Size Fractions

Standard Conditions: EPSC Frother 0.3 kg/t, Diesel Collector, Decreasing Liquid Level

Test No.	Test Conditions: Size Fraction mesh	Size Fraction mm	Diesel Dosage kg/t	Cumulative Concentrate Analyses: 30 Sec % YLD	30 Sec % ASH	60 Sec % YLD	60 Sec % ASH	90 Sec % YLD	90 Sec % ASH	180 Sec % YLD	180 Sec % ASH	Tails % YLD	Tails % ASH	Feed Reconst % ASH	Carbon Recovery %
37	28x100	0.6x0.15	0.1	60.5	6.2	64.2	6.4	65.6	6.5	67.3	6.6	37.7	34.9	15.8	74.7
41	28x100	0.6x0.15	0.2	66.8	6.9	72.5	7.2	74.6	7.3	76.8	7.4	23.2	42.5	15.6	84.2
36	28x100	0.6x0.15	5.0	7.6	8.7	11.3	8.2	15.1	7.9	20.9	7.6	79.1	17.3	15.3	22.8
39	-100	0.15x0	2.28	61.6	13.6	65.3	14.2	66.9	14.6	68.7	15.1	31.3	67.6	31.5	85.2
35	-100	0.15x0	5.0	62.4	13.1	66.4	13.8	68.1	14.3	70.3	14.9	29.7	71.0	31.5	87.4
40	-100	0.15x0	12.67	67.8	14.6	70.7	15.2	72.3	15.8	74.4	16.6	25.6	75.2	31.6	90.7
24	Full Size Consist	0.6x0	1.00	15.7	7.6	26.8	7.2	38.1	7.2	63.5	8.3	36.5	43.9	21.3	73.9
34	Full Size Consist	0.6x0	5.00	61.8	8.6	73.0	9.2	76.7	9.7	79.2	10.2	20.8	62.7	21.1	90.1
	Reconstituted 0.6 x 0 (0.6 x 0.15 + 0.15 x 0 Fractions)														
(37+39)	reconst.	0.6x0	0.94	60.9	9.0	64.6	9.4	66.1	9.6	67.9	9.9	32.1	47.4	21.9	78.3
(41+39)	reconst.	0.6x0	1.00	64.8	9.5	69.8	9.9	71.7	10.1	73.7	10.4	26.3	52.2	21.7	84.3
(37+35)	reconst.	0.6x0	1.98	61.2	8.8	65.1	9.2	66.6	9.5	68.5	9.8	31.5	48.7	21.9	79.1
(41+35)	reconst.	0.6x0	2.04	65.1	9.3	70.2	9.8	72.1	10.0	74.3	10.3	25.7	53.4	21.7	85.1
(37+40)	reconst.	0.6x0	4.94	63.3	9.4	66.7	9.8	68.1	10.1	70.1	10.5	29.9	50.4	21.9	80.3
(41+40)	reconst.	0.6x0	5.00	67.2	9.9	71.8	10.3	73.7	10.6	75.9	11.0	24.1	55.1	21.7	86.3
(36+35)	reconst.	0.6x0	5.00	28.6	9.2	32.5	9.7	35.5	9.9	39.9	10.2	60.1	50.7	21.5	45.6

Table 17

Effect of Bridging Liquid Addition Rate

(0.15 mm x 0 Feed, 0.15 mm Opening Concentrate Screen)

Test	Bridging Liquid		Concentrate		Tailings		Feed	
No.	Type	Addition Rate kg/t	Yield %	Ash %	Yield %	Ash %	Reconst Ash %	Carbon Recovery %
1	Diesel	10	44.5	17.0	55.5	46.5	33.4	55.4
2		20	46.6	15.7	53.4	48.9	33.4	59.0
3		40	51.4	14.6	48.6	52.1	32.8	65.4
4		80	64.7	15.7	35.3	63.8	32.6	81.0
5		120	66.5	16.4	33.5	65.1	32.6	82.6
6		160	70.2	17.6	29.8	67.8	32.5	85.7
7		200	71.2	16.8	28.8	69.5	32.0	87.1
8	Bunker C	160	71.5	14.6	28.5	79.0	32.9	91.1
25		180	73.6	16.2	26.4	79.9	33.0	92.1
9		200	76.1	17.6	23.8	82.3	33.0	93.7

Table 18

Effect of Bridging Liquid Type

(0.15 mm x 0 Feed, 0.15 mm Opening Concentrate Screen)

Test	Bridging Liquid		Concentrate		Tailings		Feed	
No.	Type	Addition Rate kg/t	Yield %	Ash %	Yield %	Ash %	Reconst Ash %	Carbon Recovery %
6	Diesel	160	70.2	17.6	29.8	67.8	32.5	85.7
8	Bunker C	160	71.5	14.6	28.5	79.0	32.9	91.1
7	Diesel	200	71.2	16.8	28.8	69.5	32.0	87.1
9	Bunker C	200	76.1	17.6	23.8	82.3	33.0	93.7
11	Varsol	200	70.2	17.4	29.8	69.2	32.7	86.2

Table 19

Effects of Agitation Intensity and Residence Time

(0.15 mm x 0 Feed, 160 kg/t Diesel, 0.15 mm Opening Concentrate Screen)

Test No.	Agitation* Intensity rpm	Residence Time sec	Concentrate Yield %	Concentrate Ash %	Tailings Yield %	Tailings Ash %	Feed Reconst Ash %	Carbon Recovery %
15	1000	30	65.5	20.7	34.5	56.3	33.0	77.5
17	15000	30	68.6	21.1	31.4	60.4	33.3	81.1
16	1000	180	62.0	18.1	38.0	57.6	33.0	75.6
18	15000	180	66.0	17.5	34.0	64.5	33.4	81.6

*Estimated from manufacturer's data

Table 20

Effect of pH on Oil Agglomeration

(0.15 mm x 0 Feed, 160 kg/t Diesel, 0.15 mm Opening Concentrate Screen)

Test No.	pH Initial	pH Final	Concentrate Yield %	Concentrate Ash %	Tailings Yield %	Tailings Ash %	Feed Reconst Ash %	Carbon Recovery %
12	5.0	7.7	62.0	15.8	38.0	61.5	33.1	78.1
13	7.0	8.2	60.5	14.9	39.5	60.8	33.0	76.9
14	9.0	8.2	63.1	16.1	36.9	62.1	33.1	79.1

Table 21

Effect of Pulp Density on Oil Agglomeration

(0.15 mm x 0 Feed, 200 kg/t Diesel, 0.15 mm Opening Concentrate Screen)

Test No.	Pulp Density %	Concentrate Yield %	Concentrate Ash %	Tailings Yield %	Tailings Ash %	Feed Reconst Ash %	Carbon Recovery %
7	5	71.2	16.8	28.8	69.5	32.0	87.1
19	10	68.6	16.5	31.4	65.3	31.8	84.0
20	15	75.3	20.3	24.7	66.3	31.7	87.8

Table 22

Effect of Screening on Concentrate Properties

as a Function of Pulp Density

(0.15 mm Feed, 200 kg/t Diesel, 0.15 mm Opening Concentrate Screen)

Pulp Density %	Thoroughly Wet Screened Yield %	Thoroughly Wet Screened Ash %	Normally Recovered Yield %	Normally Recovered Ash %
5	24.8	4.9	71.2	16.8
15	31.2	4.8	75.3	20.3

Table 23

Effects of Re-Agglomeration and of Washing Concentrate with Water (0.15 mm x 0 Feed, 0.15 mm Opening Concentrate Screen)

Test No.	Test Conditions	Concentrate Yield %	Concentrate Ash %	Carbon Recovery %
20B	15% Pulp Density (200 kg/t Diesel)	77.8	21.7	89.1
21	Re-Agglomerate Once	63.0	13.2	80.0
22	Re-Agglomerate Twice	56.9	9.6	75.2
8	5% Pulp Density (160 kg/t Bunker C)	71.5	14.6	91.1
23	Re-Agglomerate Once	63.7	9.8	85.8
8	5% Pulp Density (160 kg/t Bunker C)	71.5	14.6	91.1
24	Wash Concentrate with 500 ml water	66.1	10.9	87.8

Table 24

Preliminary Agglomeration Tests Using 0.6 mm x 0 Feed and 0.85 mm Opening Screen to Recover Agglomerates (All Results are from Single Runs)

Test No.	Bridging Liquid Type	Bridging Liquid Addition Rate kg/t	Concentrate Yield %	Concentrate Ash %	Tailings Yield %	Tailings Ash %	Feed Reconst Ash %	Carbon Recovery %
32	None	0	19.5	15.4	80.5	23.5	21.9	21.1
33	Diesel	20	72.2	16.9	27.8	36.9	22.5	77.4
34	Diesel	100	66.5	13.3	33.5	38.9	21.8	73.7
35	Heavy Oil	20	71.0	16.8	29.0	33.9	21.8	75.5
36	Heavy Oil	100	64.7	16.0	35.3	30.8	21.2	69.0
37	Heavy Oil + Bunker C	40 30	82.3	11.2	17.7	68.4	21.3	92.9

Table 25

Agglomeration of 0.6 mm x 0 Feed Using 0.15 mm Opening Screen For Agglomerates Recovery

Test No.	Bridging Liquid Type	Bridging Liquid Addition Rate kg/t	Concentrate Yield %	Concentrate Ash %	Tailings Yield %	Tailings Ash %	Feed Reconst Ash %	Carbon Recovery %
38	None[1]	0	63.3	9.5	36.7	41.0	21.1	72.6
39	Diesel	10	75.6	11.1	24.4	54.0	21.6	85.7
41	Bunker C	10	75.8	12.3	24.2	50.9	21.4	84.5
40	Diesel	20	77.2	10.8	22.8	57.2	21.3	87.6
44	Bunker C	80	85.7	12.0	14.3	77.5	21.3	95.9
46	Bunker C	40						
	+ Coal Tar	80	83.9	12.3	16.1	68.4	21.4	93.5
45	Bunker C/	80						
	Coal Tar[2]	120	81.7	8.6	18.3	78.2	21.3	94.9
42	Diesel[3]	200	83.6	10.8	16.4	72.3	20.9	94.2

1 Feed contains 64.8% plus 0.15 mm material at 14.2% ash. After conditioning and 3 minutes of agitation the plus 0.15 mm material is reduced to 48.5% at 10.3% ash.

2 Bunker C was added in the first stage (Test 44). The agglomerates were recovered on the 0.15 mm opening screen, then re-agglomerated in fresh water. The coal tar was added in this second stage. The 0.15 mm opening screen was again used for final concentrate recovery.

3 Pulp density was 10%. The agglomerates were recovered and then re-agglomerated in a second stage. All of the diesel was added in the first stage.

Table 26

Particle Size Reduction and Ash Liberation Caused by the Intensive Agitation During Oil Agglomeration (0.6 mm x 0 Feed, No Bridging Liquid, Thorough Wet Sieving on 0.15 mm Opening Sieve)

Condition	Plus 0.15 mm Fraction	
	Yield %	Ash %
Feed	64.8	14.2
3 min conditioning plus 3 min agitation	48.5	10.3
3 min conditioning plus 6 min agitation	45.7	8.7

Table 27

Oil Agglomeration Tests Done at Optimum Conditions

Optimization Test #1

Feed: 0.6 mm x 0
Bridging Liquid: 200 kg/t Diesel
Pulp Density: 5%
Concentrate Screens: 0.6, 0.3 and 0.15 mm Opening
Thorough Wet Screening of Concentrate

Test Results:

	Size Fraction mm	Yield %	Ash %	Carbon Recovery %
Concentrate	+ 0.6	5.0	5.0	6.0
	0.6 x 0.3	43.4	6.0	51.9
	0.3 x 0.15	21.2	14.3	23.1
Cum. Conc.	0.6 x 0.15	69.6	8.5	81.0
Tailings	-0.15	30.4	51.0	19.0
Feed (reconst.)	0.6 x 0	100	21.4	100

Table 27 continued

Oil Agglomeration Tests Done at Optimum Conditions

Optimization Test #2

Feed:	0.6 mm x 0
Bridging Liquid:	160 kg/t Bunker C
Pulp Density:	5%
Concentrate Screens:	0.6, 0.3 and 0.15 mm Opening

Thorough Wet Screening of Concentrate

Test Results:

	Size Fraction mm	Yield %	Ash %	Carbon Recovery %
Concentrate	+ 0.6	40.3	7.0	47.6
	0.6 x 0.3	32.9	8.6	38.2
	0.3 x 0.15	10.6	23.0	10.4
Cum. Conc.	0.6 x 0.15	83.8	9.7	96.2
Tailings	-0.15	16.2	81.3	3.8
Feed (reconst.)	0.6 x 0	100	21.3	100

Table 27 continued

Oil Agglomeration Tests Done at Optimum Conditions

Optimization Test #3

Feed:	0.15 x 0
Bridging Liquid:	200 kg/t Bunker C
Pulp Density:	5%
Concentrate Screens:	0.6, 0.3 and 0.15 mm Opening
Thorough Wet Screening of Concentrate	

Test Results:

	Size Fraction mm	Yield %	Ash %	Carbon Recovery %
Concentrate	+ 0.6	3.7	8.2	5.1
	0.6 x 0.3	42.6	7.8	58.6
	0.3 x 0.15	16.7	9.4	22.6
Cum. Conc.	0.6 x 0.15	63.0	8.2	86.3
Tailings	-0.15	37.0	75.3	13.7
Feed (reconst.)	0.6 x 0	100	33.0	100

Table 28

Effect of Bridging Liquid Type on Agglomeration Flotation

(0.6 mm x 0 Feed)

Test No.	Bridging Liquid Type	Bridging Liquid Addition Rate kg/t	Concentrate Yield %	Concentrate Ash %	Tailings Yield %	Tailings Ash %	Feed Reconst Ash %	Carbon Recovery %
2	Diesel	5	84.7	11.9	15.3	77.6	21.9	95.6
5	Bunker C	5	81.6	11.1	18.4	68.3	21.6	92.5
3	Diesel	10	86.2	12.2	13.8	84.1	22.1	97.2
6	Bunker C	10	87.7	12.6	12.3	86.9	21.8	97.9

Table 29

Effect of Bridging Liquid Addition Rate on Agglomeration Flotation

(0.6 mm x 0 Feed, Diesel Bridging Liquid)

Test No.	Bridging Liquid Addition Rate kg/t	Concentrate Yield %	Concentrate Ash %	Tailings Yield %	Tailings Ash %	Feed Reconst Ash %	Carbon Recovery %
1	1.0	42.9	12.1	57.1	28.4	21.4	47.9
2	5.0	84.7	11.9	15.3	77.6	21.9	95.6
3	10.0	86.2	12.2	13.8	84.1	22.1	97.2
4	20.0	86.5	10.9	13.5	85.7	21.0	97.5

Table 30

Effect of Feed Size Consist on Agglomeration Flotation

(Diesel Bridging Liquid)

Test No.	Feed Size Consist mm	Bridging Liquid Addition Rate kg/t	Concentrate		Tailings		Feed	
			Yield %	Ash %	Yield %	Ash %	Reconst. Ash %	Carbon Recovery %
3	0.6 x 0	10	86.2	12.2	13.8	84.1	22.1	97.2
7	0.15 x 0	10	76.0	17.8	24.0	80.8	32.9	93.1
4	0.6 x 0	20	86.5	10.9	13.5	85.7	21.0	97.5
8	0.15 x 0	20	77.0	18.2	23.0	82.1	32.9	93.9

Table 31

Comparison of Flotation, Agglomeration Flotation and Agglomeration

Method	Test No.	Bridging Liquid or Collector Addition Rate kg/t	Feed Size Consist mm	Concentrate Yield %	Concentrate Ash %	Tailings Yield %	Tailings Ash %	Feed Reconst Ash %	Carbon Recovery %
Flotation	24	1.0	0.6 x 0	63.5	8.3	36.5	43.9	21.3	74.0
Agg. Flot.	1	1.0	0.6 x 0	42.9	12.1	57.1	28.4	21.4	47.9
Flotation	34	5.0	0.6 x 0	79.2	10.2	20.8	62.7	21.1	90.1
Agg. Flot.	2	5.0	0.6 x 0	84.7	11.9	15.3	77.6	21.9	95.6
Agg. Flot.*	5	5.0	0.6 x 0	81.6	11.1	18.4	68.3	21.6	92.5
Flotation	40	12.7	0.15 x 0	74.4	16.6	25.6	75.2	31.6	90.7
Agg. Flot.	7	10.0	0.15 x 0	76.0	17.8	24.0	80.8	32.9	93.1
Agglomeration	1	10.0	0.15 x 0	44.5	17.0	55.5	46.5	33.4	55.4
Agg. Flot.	3	10.0	0.6 x 0	86.2	12.2	13.8	84.1	22.1	97.2
Agglomeration	39	10.0	0.6 x 0	75.6	11.1	24.4	54.0	21.6	85.7
Agg. Flot.	4	20.0	0.6 x 0	86.5	10.9	13.5	85.7	21.0	97.5
Agglomeration	40	20.0	0.6 x 0	77.2	10.8	22.8	57.2	21.3	87.6
Agg. Flot.	8	20.0	0.15 x 0	77.0	18.2	23.0	82.1	32.9	93.9
Agglomeration	2	20.0	0.15 x 0	46.6	15.7	53.4	48.9	33.4	59.0
Agg. Flot.*	6	10.0	0.6 x 0	87.7	12.6	12.3	86.9	21.8	97.9
Agglomeration*	41	10.0	0.6 x 0	75.8	12.3	24.2	50.9	21.4	84.5

*Bunker C Bridging Liquid (all other tests are with diesel bridging liquid/collector)

FIGURE 1
RESULTS USING DIFFERENT FROTHERS
Standard Conditions:
0.3kg/t frother
1.0kg/t diesel

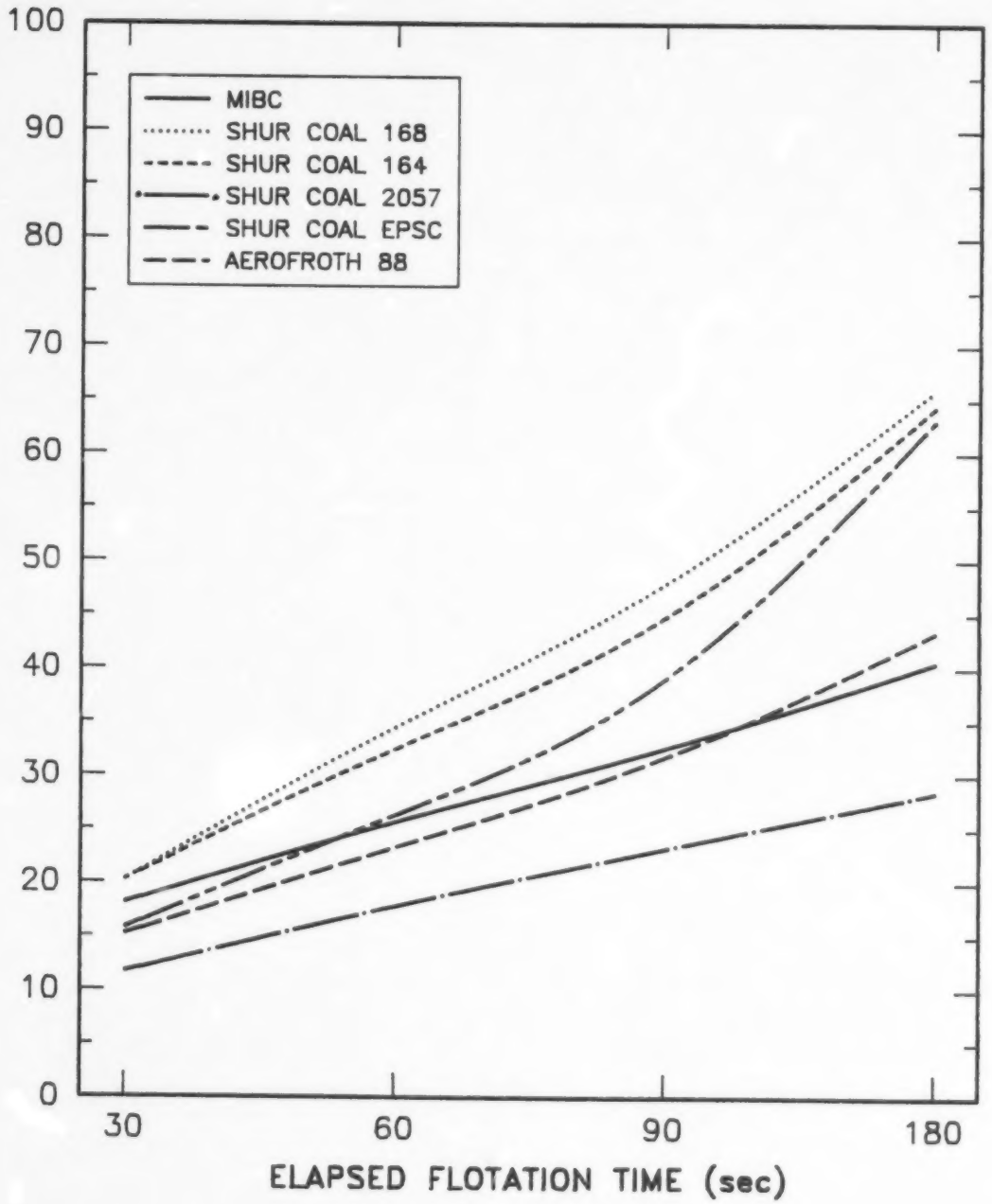


FIGURE 2
EFFECT OF COLLECTOR TYPE
Standard Conditions:
0.3kg/t MIBC
1.0kg/t Collector

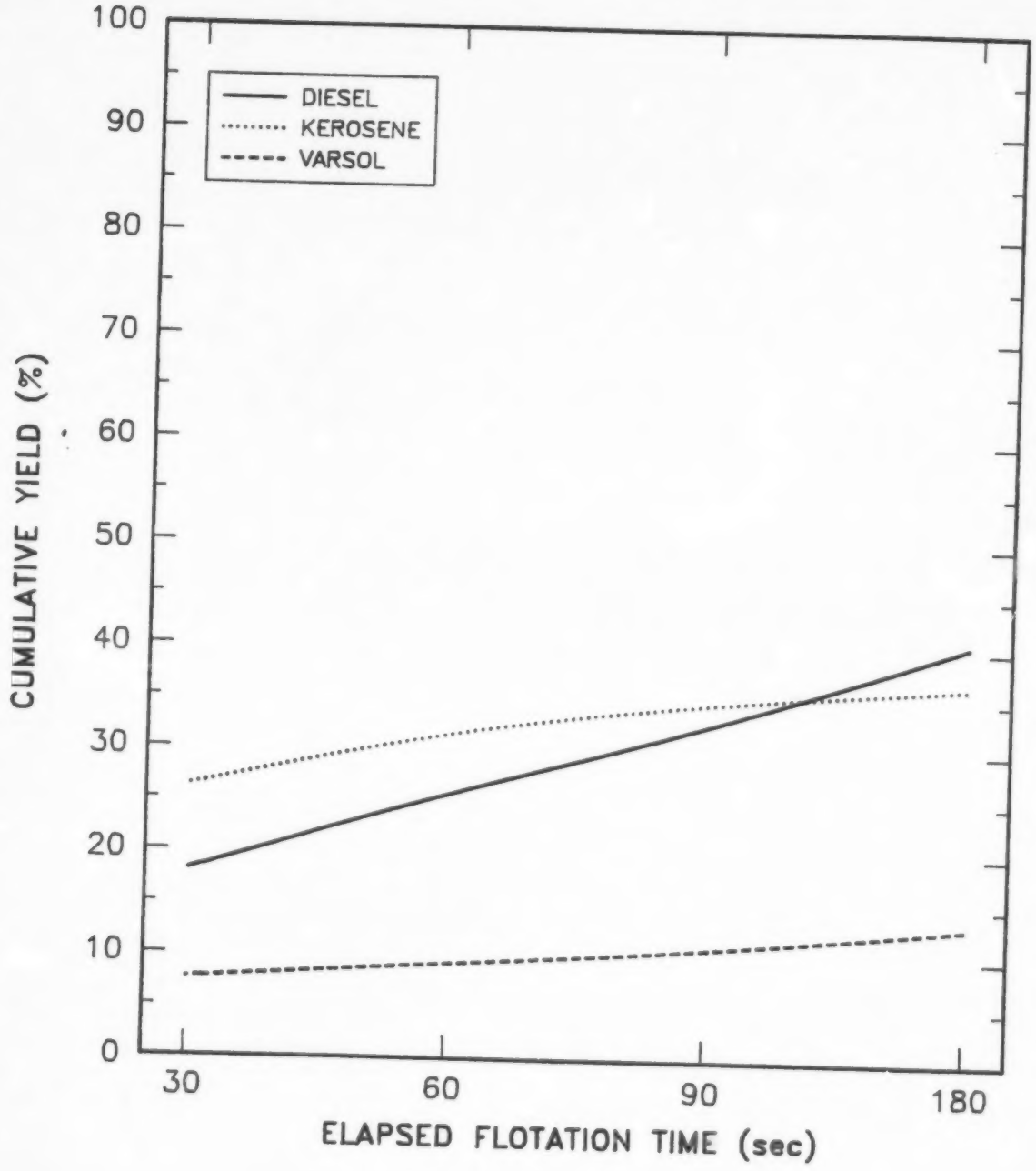


FIGURE 3
EFFECT OF DIESEL ADDITION RATE
Standard Conditions:
0.3kg/t MIBC

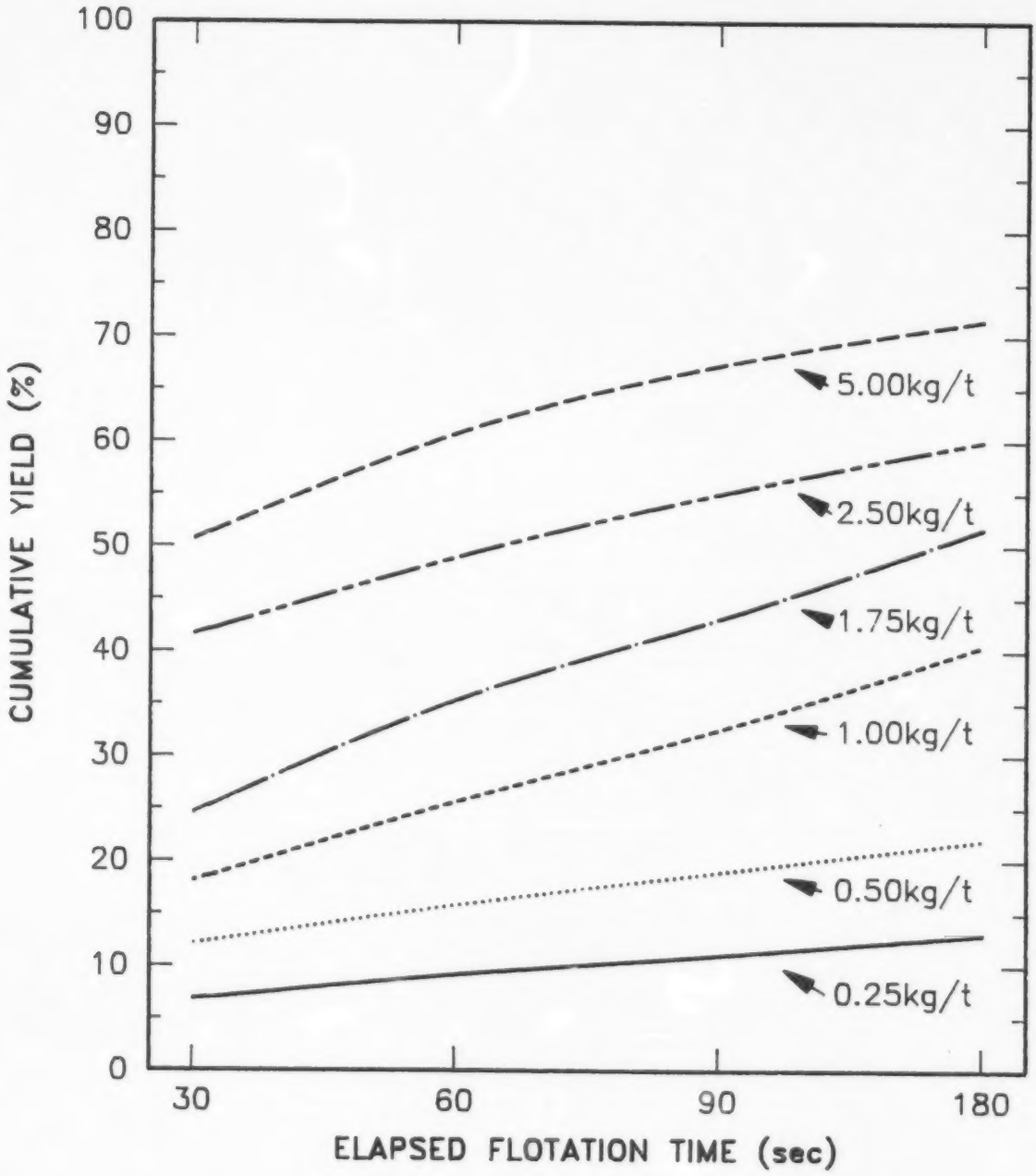


FIGURE 4
EFFECT OF SPLIT SIZE FLOTATION

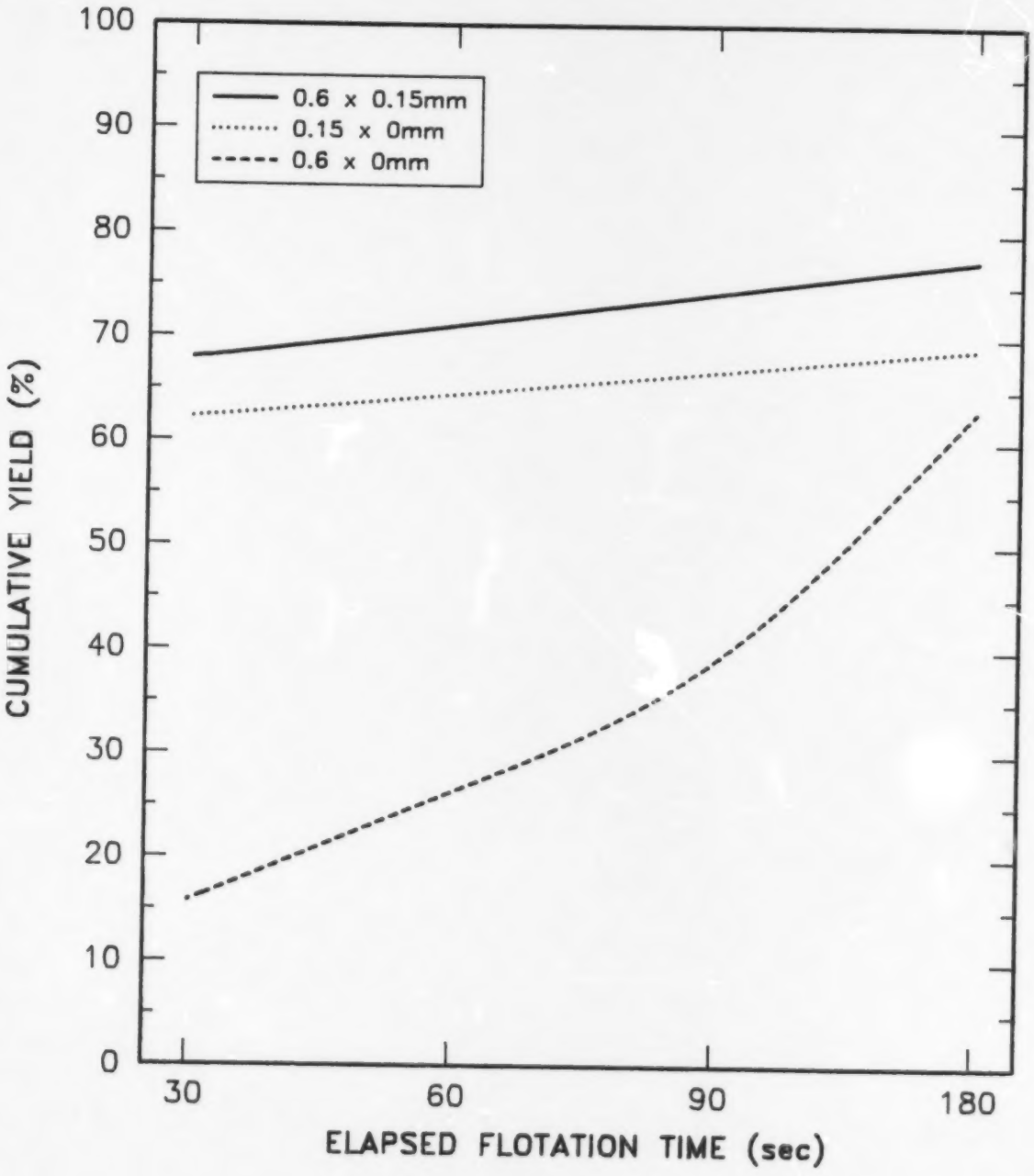


FIGURE 5
EFFECT OF DIESEL ADDITION RATE ON
CARBON RECOVERY AND CONCENTRATE ASH
OF AGGLOMERATES

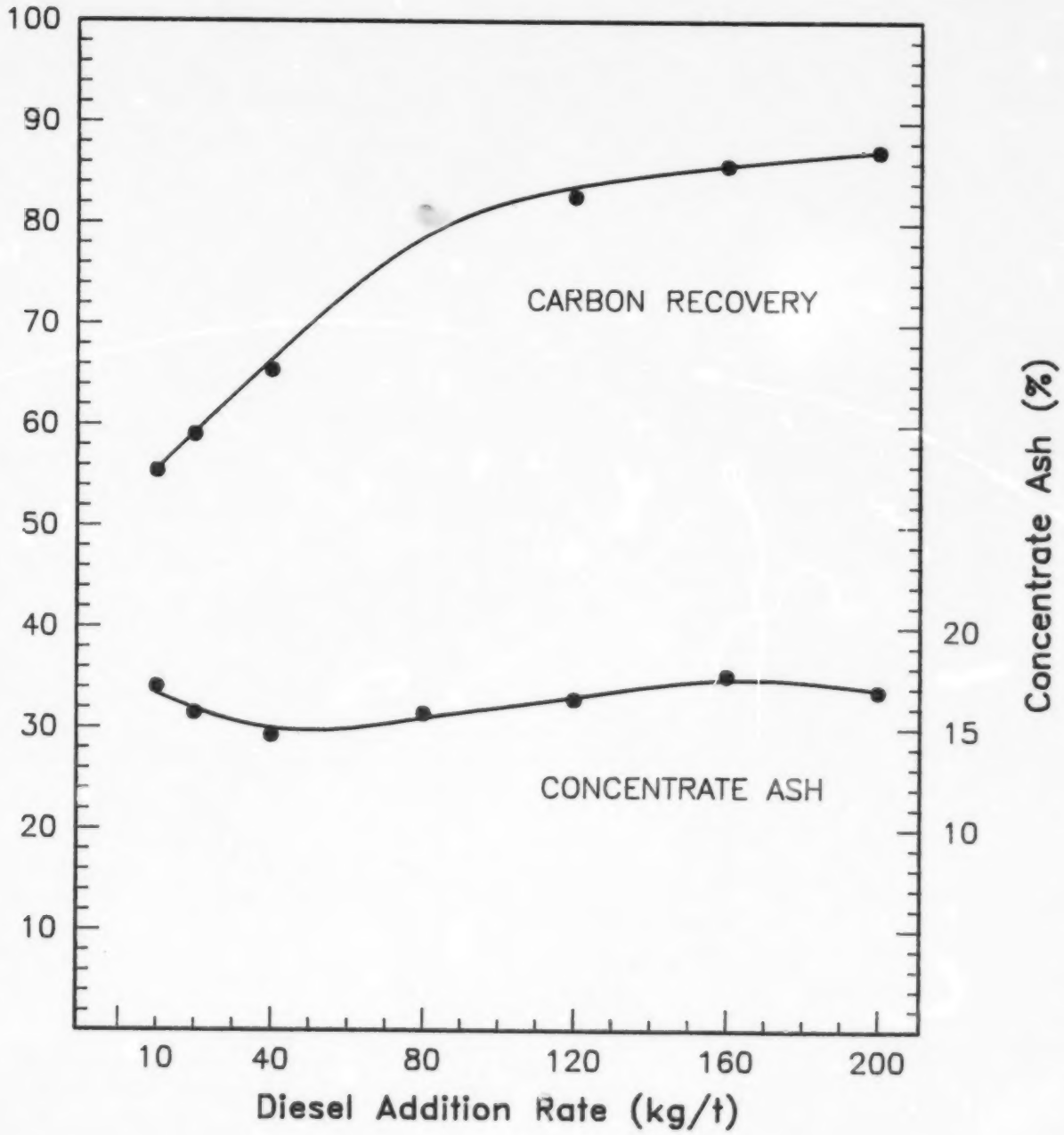


FIGURE 6
COMPARISON OF EXPERIMENTAL RESULTS OBTAINED FOR 0.6mm X 0 FEED
UNDER OPTIMUM TEST CONDITIONS

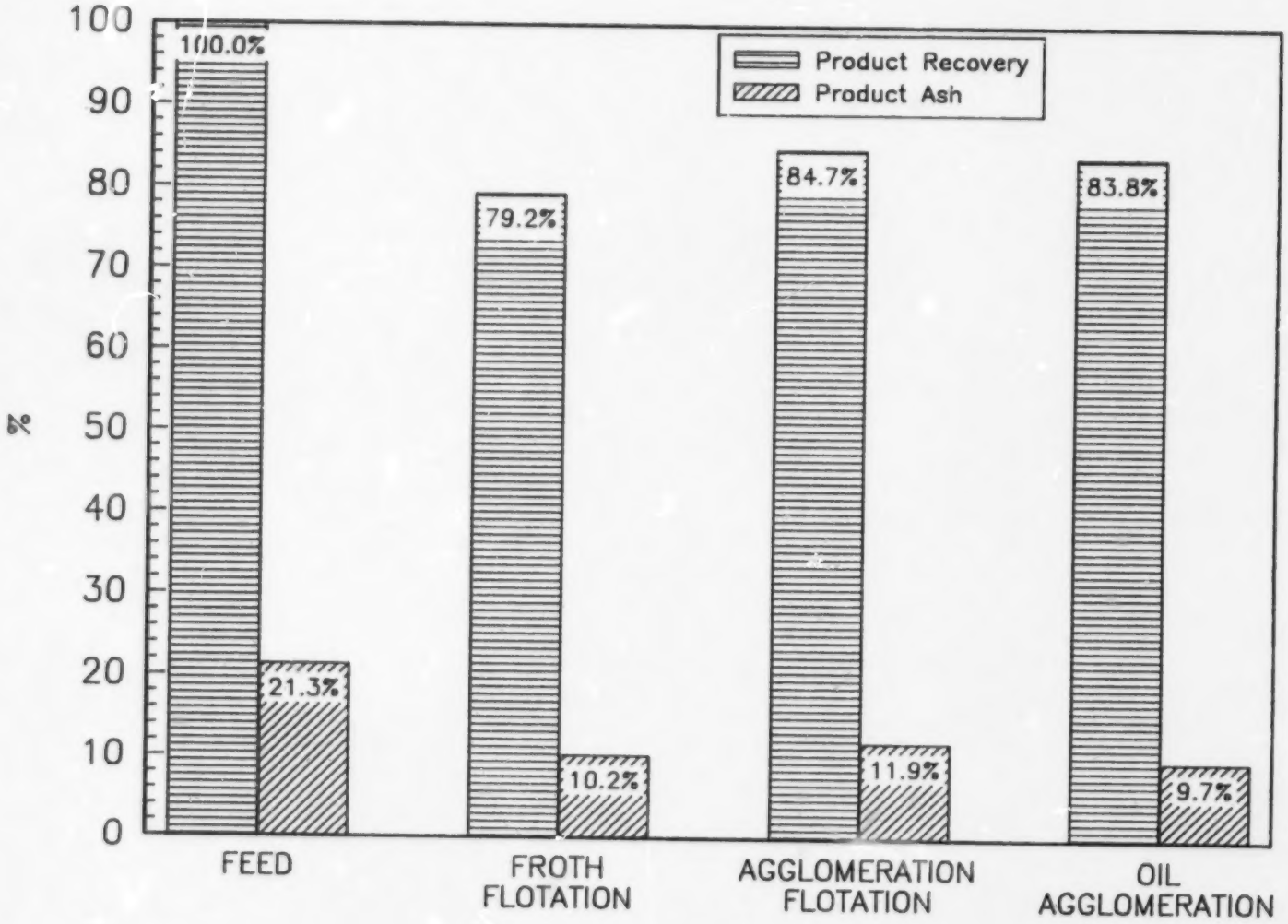
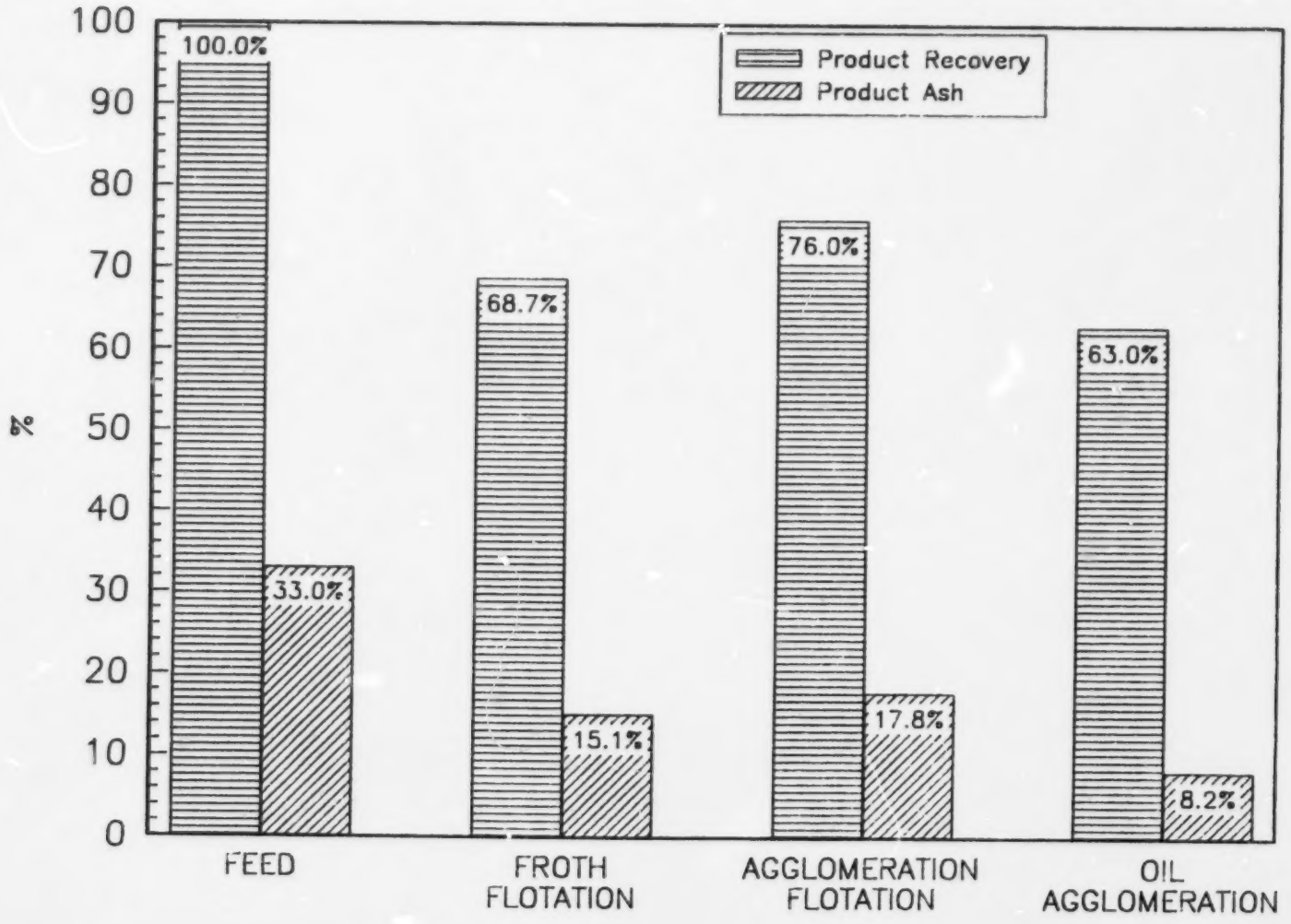


FIGURE 7
COMPARISON OF EXPERIMENTAL RESULTS OBTAINED FOR 0.15mm X 0 FEED
UNDER OPTIMUM TEST CONDITIONS



Appendix 1

Work Statement of Research Contract
030.SQ.23440-8-9045

"Beneficiation and Enlargement of Anthracite Fines

STATEMENT OF WORK

TITLE: BENEFICIATION AND ENLARGEMENT OF ANTHRACITE FINES [Part of EMR's 50/50 Cost-Shared Energy Conversion Program and Part of the Program of the Federal Panel on Energy R & D (PERD)]

The work in this Research Program will be carried out in six tasks. The program is expected to take eight months to complete.

Each task is described in the following sections.

TASK NO.1 SAMPLE ACQUISITION AND CHARACTERIZATION

A 100 kg sample of minus 0.6 mm raw anthracite fines will be obtained. Alternatively, 100 kilograms of raw coal will be obtained and crushed to minus 0.6 mm. Gulf Canada will be responsible in selecting samples with particular consideration given to sample history. Samples will be homogenized to obtain representative sub-samples for the experimental program. The sample will be characterized with respect to:

1. proximate analysis and ultimate analysis
2. maceral analysis
3. calorific value
4. hardgrove grindability index
5. size consist
6. ash content of each size fraction
7. washability (0.6 X 0.15 and 0.15 X 0.045 mm fractions only)

TASK NO.2 LITERATURE SURVEY OF FLOTATION AND AGGLOMERATION OF ANTHRACITE FINES

A comprehensive literature survey of the applications of flotation and or agglomeration to this highly matured coal is expected to define the ranges of operating variables which would likely give optimum results. Reagents and conditioning time will be given particular emphasis because of the low hydrogen/carbon ratio of anthracite. Other processing variables such as size consist, pulp density, etc. will be reviewed for the definition of experimental conditions. A target ash content for anthracite fines used in this study will also be defined after the survey.

TASK NO.3 FROTH FLOTATION

A WEMCO flotation cell will be used for this task. Some minor modifications such as installation of a level control will be required to ensure all the experiments be carried out in the same manner. Reproducibility of the experiments will also be established prior to the experimental program.

Using MIBC (Methyl isobutyl carbinol) frother and diesel collector as the base case reagents, tests will be done to determine the effects of:

1. frother type and dosage
2. collector type and dosage
3. promoter type and dosage
4. conditioning time
5. pulp density
6. flotation residence time
7. particle size
8. pH
9. staged flotation (rougher, cleaner)

The findings from the literature review will influence the levels of these variables and, in particular, the selection of reagents. About 100 tests will be required (including duplicates) to adequately evaluate the effects of the stated variables. Once the effects have been determined a series of tests will be done to optimize the process.

The ash and yields of the products from each test will be determined and used as the basis for evaluating results. BTU recovery will be determined for those tests having the highest carbon yields.

TASK NO.4 MICRO-AGGLOMERATION & COARSE AGGLOMERATION

Laboratory scale agglomeration tests will be done at low oil contents (1-2%) to produce micro-agglomerates. Agglomeration will be done in the WEMCO flotation cell. The micro-agglomerates will be recovered by screening. These tests will investigate the effects of:

1. oil content
2. oil type
3. residence time
4. agitation intensity
5. pulp density
6. pH

As in Task 3, the findings of the literature will influence the testwork to be done in this task. About 50 tests will be required to adequately evaluate the effects of the process variables.

Products will be evaluated on the basis of ash content and yield, as well as BTU recovery for the tests that give high carbon yields.

To a large extent the quantity of oil used in agglomeration dictates the size of the agglomerates produced. Thus, it is possible to produce relatively coarse agglomerates in a stirred tank. Specific tests will include:

1. Use of one oil for the entire process, such as the best oil used in micro-agglomeration.
2. Use of two oils for the process, such as micro-agglomeration with a light oil followed by coarse agglomeration with a heavy oil.
3. Effect of agitation intensity.

About 25 tests will be required for the coarse agglomeration tests. Products from the coarse agglomeration tests will be evaluated in terms of ash and moisture content, and process yield. BTU yield, wet and dry agglomerate strength, and agglomerate size will be determined on selected samples.

TASK NO.5 AGGLOMERATION-FLOTATION

The optimized conditions of Task No. 4 will be used to produce micro-agglomerates for subsequent froth flotation. The optimized conditions established in Task No. 3 will be used for the froth flotation. Since the micro-agglomerates

will be somewhat different from the natural coal, some optimization of the froth flotation stage will be required. About 25 tests will be required for this task. Products from the combined agglomeration-flotation process will be evaluated on the basis of ash content and yield, as well as BTU recovery for selected tests.

TASK NO.6 EVALUATION OF RESULTS AND FINAL REPORT

Results obtained from all Tasks will be compiled, compared, and analyzed. Variables to be controlled will be listed and optimum conditions defined.

Data will be supported by Tables, graphs, and charts as required.

Appendix 2

Literature Review

2.0 LITERATURE REVIEW

The primary objective of the literature review was to identify suitable process variables and reagents for the experimental section of the project. Particular emphasis was placed on the literature pertaining to anthracite. An in-depth review was beyond the scope of the project, considering the voluminous literature pertaining to flotation and the fact that three somewhat similar processes were being considered: flotation, agglomeration with and without flotation.

The major similarity amongst the three processes is that they are surface chemistry dependent. The basic separating mechanism is the difference in the surface chemistry of the coal and ash constituents, as opposed to gravimetric processes that separate on the basis of specific gravity differences between the coal and ash particles.

The objective of flotation is the preferential adherence of coal particles to air bubbles rising through the slurry. A fundamental requirement is that the coal adhere to the air bubbles. The coal laden bubbles rise to the surface of the flotation cell where they form a froth which can be skimmed off the surface. The ash particles remain in the aqueous phase and get transported out of the flotation cell along with the bulk of this phase. Most coals are hydrophobic (water fearing) and prefer an air-to-coal interface rather than a water-to-coal interface. The hydrophilic (water loving) ash particles prefer to remain wetted by the water and consequently have less tendency to adhere to the air bubbles. The degree of hydrophobicity of the coal often dictates how well it floats. Flotation practice often requires adjustment of both chemical and physical parameters in order to improve coal flotation.

Oil agglomeration also utilizes the hydrophobic nature of coal and the hydrophilic nature of ash to separate the two. In oil agglomeration a hydrocarbon bridging liquid or oil is added to the slurry and the oil preferentially adheres to the coal while the hydrophilic ash remains in the aqueous phase. The oil at the coal surface serves as a liquid bond that holds coal particles together to form a larger

agglomerated particle. These agglomerates are subsequently separated from the ash bearing aqueous phase by trapping the agglomerates on a screen whose openings are intermediate in size between the agglomerates and the ash particles.

Agglomeration flotation combines the size enlargement mechanism of oil agglomeration with the separating mechanism of froth flotation.

These simplistic descriptions of the three processes ignore the many chemical and physical parameters that influence the performance of these processes. The following briefly summarizes the important chemical and physical parameters identified in the literature pertaining to the three processes in question.

2.1 Chemical Parameters of Froth Flotation

2.1.1 Coal Floatability

As suggested above, the relative hydrophobicity of the coal versus the ash has a significant effect on the flotation and oil agglomeration processes. In general, hydrophobicity increases as coal rank increases. Functional groups in coal, such as carboxyl (-COOH) and hydroxyl group (-OH), reportedly reduce hydrophobicity. Table A2.1 combines data from the literature (Mishra et al. 1982, Townsend 1985) which suggests that as coal rank increases from lignite to anthracite the hydrophobicity should increase due to a reduction in hydrophilic carboxyl (-COOH) and hydroxyl groups (-OH). Contact angle, which measures the angle between the coal surface and the air bubble at the interface, has been used to measure the relative hydrophobicity of coals. Data from contact angle measurement suggests that anthracite is not as hydrophobic as semi-anthracite or low volatile bituminous coals. Figures A2.1 and A2.2 also suggest that hydrophobicity/floatability is not strictly a function of rank, with anthracite being about as floatable as medium volatile bituminous coal.

For all coals, regardless of rank, floatability decreases as the degree of coal oxidation increases. Oxidation increases the -OH and CO groups which make the coal more hydrophilic while reducing the $-CH_3$, $-CH_2$ and -CH groups which are hydrophobic (Mishra 1982).

A coal's floatability can be altered by the quantity, type, and nature of association of its ash constituents. Free or liberated ash constituents can reduce floatability by coating the coal's surface. Clay slimes, particularly bentonitic clays, are notorious for this. Similarly, ash constituents that are still physically bound to the coal particles are also capable of reducing floatability.

Numerous studies have been made of the floatability of coal lithotypes (Arnold and Aplan 1986, Sarkar et al. 1984), most of which suggest that vitrinite is the most floatable coal constituent. Mishra (1982) suggests that this is due to the highly aromatic structure of vitrinite.

2.1.2 Chemical Reagents

A wide variety of chemicals are used in flotation to increase process efficiency, improve yield, reduce product ash, increase tailings ash, improve kinetics, etc. The following discussions group these chemical reagents according to the classification used by Wheeler and Keys (1987): frothers collectors, and conditioning agents.

2.1.2.1 Frothers

Frothers are generally heteropolar surface active chemicals that reduce surface tension. Their role is twofold:

a. to decrease bubble size
b. to produce a stable froth

By maintaining small bubble size the surface to volume ratio of the air bubble increases, thereby increasing the chances of coal particle-air contact as well as increasing the carrying capacity per unit volume of air. A stable froth is one which will not break down and subsequently release its coal particles back to the slurry. On the other hand, the froth must not be too stable such that it creates handling problems once it has been removed from the flotation cell.

Many frothers are identified in the literature. Table A2.2 provides a list of frothers. Methyl isobutyl carbinol (MIBC) is the best known frother but is being replaced in the industry by new specialized frothers. Most flotation studies use MIBC as the reference frother.

Frother consumption is typically in the range 0.1 to 0.3 kg of frother per tonne of solids. Several authors indicate that since the frother acts at the air-water interface its addition should not be based on solids content but on water flow rate/volume (Swanson et al. 1984, Wheeler and Keys 1987) Swanson et al. recommend frother rates of 0.1 to 0.5 kg/tonne of water. Also, one would expect that frother consumption would increase as air rate increases.

Basing frother consumption on water rate and/or air rate assumes that the frother does not adsorb onto the coal, which is not necessarilly the case (Rosenbaum pp. 125-130 1981, Mishra 1982) although it has been reported that adsorption of MIBC is negligible at the concentrations and residence times used in conventional flotation (Aston et al. 1983).

Newer proprietary commercial frothers are often sold with a promoter (see section 2.1.2.3) in their formulation. This promoter does adsorb at the coal surface, so consumption of these frothers would definitely increase in proportion to the solids floated.

Generally, the effect of increasing frother dosage is one of increasing yield; however, overdosing of frother can result in decreased yield and increased product ash (Swanson et al. 1984, Aston et al. 1983)..

With respect to anthracite flotation, the following frothers were identified in the literature:

- MIBC
- pine oil
- cresylic acid
- glycols

Glycols, in particular, were recommended for anthracite flotation (Keys 1988).

2.1.2.2 Collectors

Collectors are used to increase the hydrophobicity of the coal surface. Collectors are organic compounds that adsorb at the coal-water interface. Typical collectors are: diesel oil, kerosene, fuel oil, and creosote. Collector consumption varies within the range 0.5 to 2 kg/tonne of solids. Generally, yield increases as collector addition rate increases. At very high addition rates product ash increases.

Collector viscosity has been identified as an important collector property (Mishra 1982, Townsend 1985). The lower the viscosity, the easier it is to disperse the collector. Thus, lower collector viscosity usually results in improved flotation yield and reduced product ash (Townsend 1985).

2.1.2.3 Conditioning Agents

Conditioning agents can be classified according to their function. With respect to coal flotation, the important classifications of conditioning agents are:

- promoters
- emulsifiers

Promoters are usually heteropolar compounds that improve the attachment of the neutral collector to the negatively charged coal. Figure A2.3 illustrates this effect.

Numerous chemicals have been investigated as promoters, of which the following are but a few:

- amines
- esters

- alkoxylated fatty acids
- ethoxylated fatty acids
- sulphhydril compounds

Many proprietary reagents are available that contain promoters to enhance flotation performance. Often these reagents are sold as frothers and are used in place of MIBC, yet their effectiveness is largely due to the promoter included in the formulation.

Promoters are particularly usefull for difficult to float coals, which are generally considered to be lower rank coals or oxidized coals. Many hydrophilic coals cannot be floated without the use of promoters. In general, the more hydrophilic the coal, the less selective is the promoter that is capable of floating the coal.

Emulsifying agents assist in dispersing the collector. This results in improved flotation efficiency through improved flotation kinetics and more efficient spreading of the collector to all coal particles. As with promoters, emulsifying agents are particularly beneficial in floating poorly floating coals. They are also useful in poorly designed flotation circuits, particularly those circuits with insufficient residence time.

Emulsifying agents are often included with promoters in the newer proprietary commercial frothers. Emulsifying agents mentioned in the literature include tensides (Stahl 1985) as well as sulfosuccinates and ethoxylated alkyl phenols (Wheeler and Keys, 1987). Analkyl phenol ethoxylate was used to emulsify fuel oil in the flotation of anthracite. Flotation yield at 0.25 kg/t fuel oil with emulsification was equivalent to yield without emulsification at 0.5 kg/t fuel oil (Wheeler and Keys 1987). Townsend (1985) presents results showing that a non-ionic emulsifier (unspecified) produced higher yield and lower product ash than an anionic emulsifier. The improved flotation performance was attributed to enhanced flotation of the coarser particles.

2.1.3 pH

pH modifiers are sometimes classed as conditioning agents. A significant amount of work has been done on the effects of pH in flotation. These studies invariably relate the effect of pH to the electrical surface properties of the coal and chemical reagents (Laskowski 1986).

While there is no doubt that pH does affect flotation performance, the effect is not consistent. Some studies indicate that optimum flotation behaviour occurs at acidic pH (Wheeler and Keys 1987) while others indicate that alkaline pH is best (Townsend 1985)

Williams and Unlee (1987) show that maximum contact angle for a West Wales anthracite is obtained at a pH range of about 6 to 7. Regardless of the optimum pH, highly acidic or alkaline slurries are to be avoided in commercial practice due to the undesireable effects on process equipment as well as on other pH sensitive process such as tailings thickening.

2.2 Physical Parameters of Froth Flotation

Physical parameters include coal and ash physical properties, collector physical properties, physical parameters of the flotation system such as cell design, impeller design, etc, and physical process variables such as pulp density, air rate, etc. The most significant of these physical parameters are discussed below.

2.2.1 Coal Particle Size

Coal particle size has a significant effect on flotation performance. Although some authors suggest that there is an optimum particle size for flotation, about 0.02 to 0.25 mm (Mishra et al 1983), 0.1 to 0.3 mm (Keys 1984), 0.05 to 0.2 mm (Swanson et al 1984), most suggest that the optimum size is dependent upon the floatability of the coal. In particular, the coal's floatability has a significant effect on the maximum particle size that can be floated. Wheeler and Keys (1987) indicate that particle density also plays a role, with coarse dense particles being

more difficult to float than less dense coarse particles. Thus, coarse anthracite would be more difficult to float than coarse particles of lower rank due to anthracite's greater density.

Several authors indicate that fine particles affect the flotation response of the coarser particles because the fines preferentially adsorb most of the collector. Recommended methods of overcoming this undesireable effect include staged addition of reagents (Firth et al. 1978), use of improved or stronger frothers and/or promoters (Mishra et al. 1983, Keys 1984), use of emulsifying agents (Townsend 1985), higher pulp density (Keys 1984), higher collector dosage (Arnold and Aplan 1986), and separate flotation of the coarse and fine size fractions (Mishra 1983). Rao et al. (1985) found that classifying the feed into 0.50 x 0.09 and -0.09 mm fractions did not improve performance.

2.2.2 Pulp Density

Recommended pulp densities vary depending largely upon the feed particle size. Keys (1984) recommends using maximum pulp density consistent with acceptable product ash in order to maximize recovery of the coarser particles. Generally, the finer the feed particle size the lower the recommended pulp density. Typical pulp densities range from 5% to 15%. Townsend (1982) provides data which indicates an optimum pulp density of 11% for a particular coal. Wheeler and Keys (1987) suggest pulp densities of 18% or higher for 0.6 x 0.15 mm particles and 5-6% pulp density for 0.15 mm x 0 feeds.

Several authors suggest that frother addition be added on the basis of water volume and not solids (Wheeler and Keys 1987, Swanson et al 1984). At low pulp densities frother additon might not be sufficient whereas at high pulp densities frother is being added needlessly and overdosing might occur. Swanson et al (1984) suggest that some of the reported effects of pulp density are actually the effects of the increased frother addition that occurs when frother is added on a solids basis.

2.2.3 Impeller Speed

The impeller aids in dispersing the air, in mixing the flotation reagents and pulp together, and in suspending the ash particles so that they do not settle out but remain in the water and eventually get transported out of the flotation cells.

Several authors (Jowett 1983, Keys 1984) suggest that coarse particles can be displaced from the air bubbles if the turbulence in the flotation cell is too great. Thus, there is an optimum impeller speed which becomes more critical as the feed particle size increases.

2.2.4 Air Rate

The quantity of air must be sufficient to float all of the coal. Too much air will increase turbulence in the flotation cell and will physically entrain more water and ash in the froth. Membrey (n.d.) determined an optimum air rate of 4L min^{-1} in his experiments. He suggests that at lower rates, 2L min^{-1}, there are too few optimum sized bubbles because of lack of air while at higher rates, 8L min^{-1}, the impeller was flooded with air, once again resulting in a lack of optimum sized bubbles. Both yield and ash decreased at air rates above and below the optimum.

2.3 Oil Agglomeration

2.3.1 Coal Hydrophobicity

The bridging liquid in oil agglomeration acts to a certain extent like the collector in flotation. In flotation the collector wets the coal particle and then acts as the bond between the coal particle and the air bubble. In oil agglomeration the bridging liquid wets the coal particle and then acts as the bond between two coal particles. Thus, the hydrophobicity of the coal surface is as important in oil agglomeration as it is in flotation and the same factors are relevant: coal rank, coal lithotypes, surface oxidation, ash constituents.

2.3.2 Bridging Liquid

The hydrocarbon bridging liquid plays a critical role in the agglomeration process. The type and quantity of bridging liquid affects the yield and ash of the agglomerate product.

The literature suggests that "lighter" oils are more selective and produce lower product ash levels (Guerra et al 1986, Kim et al 1983). Kim et al. (1983) show that diesel oil gave better selectivity than a "heavy oil" when treating several different Korean anthracites.

Capes and Germain (1982) indicate that the higher the paraffin content of the bridging liquid the better the selectivity. Conversely, the more aromatic the bridging oil the less the selectivity.

Process schemes often recommend using the more selective oils in a first stage de-ashing agglomeration step followed by the more viscous heavy oils in the second stage step where large agglomerates are produced.

The agglomerates go through a series of phases as the bridging liquid level increases. At low levels a floc structure is created. As the level increases discrete agglomerates begin to form. At still higher levels the bridging liquid fills the pores amongst the particles, thereby displacing water and entrained ash trapped inside the agglomerates. Eventually a bridging liquid level is reached wherein a continuous coal-oil phase is created. The bridging liquid levels at which these various structures/phases occur are dependent upon the coal particle sizes. Typically, for minus 0.15 mm particles the floc phase exists up to about 5% oil level. The intermediate phase exists over a wide range of oil levels, typically 5% to 30-40%, after which the coal-oil continuous phase exists.

2.3.3 Particle Size

Oil agglomeration is usually done with minus 0.15 mm feed although there have been studies done with coarser feeds (Hazra et al 1986). Typically, the finer the particle size the lower the product ash since ash liberation increases as

particle size decreases. Guerra et al. (1986) report that minus 0.037 mm feed is required to produce low ash agglomerates from the Brazilian coals used in their study.

As particle size decreases the number of particles increases and surface area per unit weight increases. This leads to increased bridging liquid consumption since the bridging liquid must wet the coal surface. Also, the finer the feed size, the greater the number of particles that must be agglomerated together to form an agglomerate of a given size. Thus, at constant bridging liquid level, agglomerate ash and recovery will decrease as particle size decreases (Capes and Germain 1982, Hazra et al. 1986).

2.3.4 Agitation Intensity

Capes and Darcovich (1983) report that the type and intensity of mixing is the third most important variable in oil agglomeration. The high shear agitation used in oil agglomeration is required for effective dispersion of the bridging liquid and for promoting interparticle contact. Thus, increasing agitation speed is beneficial as bridging liquid viscosity increases and as bridging liquid level decreases. A number of authors suggest that the high shear agitation assists the bridging liquid in wetting the coal surface and also causes some liberation of mineral matter through particle attrition (Capes and Germain 1982, Hazra et al. 1986).

Agglomerate size is affected by agitation intensity. The more intense the agitation the finer the agglomerate size (Hazra et al. 1986). Reduced agglomerate size tends to cause reduced yield.

2.3.5 Residence Time

Sufficient residence time is required for the briding liquid to disperse and wet the coal particles and for the coal particles to contact one another. Thus, residence time must increase to compensate for reduced hydrophobicity, lower bridging liquid levels, reduced agitation intensity, increased bridging liquid viscosity, and reduced pulp density. Coals that are easy to agglomerate require

very short residence times, on the order of 30 seconds (Rosenbaum 1981), whereas under difficult conditions very long residence times are required. Kim et al. (1983) used 10 minutes and 30 minutes residence time for agglomerating Korean anthracite with diesel and heavy oil respectively. Guerra et al. (1986) used 4 minutes at 3800 rpm followed by 10 minutes at 500 rpm. Hazra et al. (1986) report that agglomerate ash content increases as retention time decreases. They also report that agglomerate recovery and size decrease as retention time decreases.

2.3.6 Pulp Density

Hazra et al. (1986) report that up to 20% pulp density has no effect on agglomerate ash content but that ash content increases significantly above 20% pulp density. They also report that increasing pulp density results in increasing tailings ash, increasing product recovery, and increasing agglomerate size, at least up to 20% pulp density. Capes and Germain (1982) suggest that high pulp density does not affect agglomeration but that low pulp density is undesireable due to the reduced chances of particle contact.

2.3.7 pH

Data presented by Capes and Germain (1982) indicates that for a Pennsylvania Lower Freeport coal a pH of 10 gives higher recovery and lower product ash than a pH of 6. They suggest that pH is a minor variable with respect to oil agglomeration.

2.4 Agglomeration Flotation

Agglomeration flotation uses low levels of bridging liquid, typically less than 5%, and high shear mixing to produce micro-agglomerates. Flotation is then used to separate the micro-agglomerates from the liberated ash suspended in the aqueous phase. It is postulated that this process would be better than flotation or agglomeration for difficult to float coals. The advantage over agglomeration is the use of low oil contents. The advantage over flotation is the benefit derived from higher collector rates (bridging liquid) and from the high shear agitation. The

process is obviously subject to all the variables that affect both flotation and agglomeration.

Rosenbaum (1981) evaluated several bridging liquids (kerosene, Nujol which is a pure hydrocarbon mineral oil, motor oil, and waste motor oil) using agglomeration flotation of low rank coals. The motor oils proved to be superior to the kerosene and Nujol. Bridging liquid consumption was evaluated at rates up to about 20 kg/t. The study indicated a significant decrease in recovery and increase in product ash as pH was reduced. This was attributed to heteroflocculation of the mineral matter and coal at the lower pH's. The study also showed a significant reduction in yield and increase in product ash as the pulp density increased above 5%.

Guerra et al. (1986) noted differing behaviour in agglomeration flotation of low and high rank coals. For the high rank coal a marginal increase in recovery occurred but product ash increased to a greater extent, both relative to flotation. For the low rank coal recovery increased significantly at essentially constant product ash. Kerosene was used as the bridging liquid/collector at rates of up to 30 kg/t. Overall, their conclusion was that agglomeration flotation gave poorer selectivity than flotation.

Table A2:1

Some Important Property Changes During Coalification Process

Properties	Lignite	Subbituminous	Bituminous	Anthracite
Carbon Content (% Wt)	60-72	72-85	85-80	93
Hydrogen (% Wt)	4-5	5-5.5	4.5-3.5	2.5
Oxygen (% Wt)	30	18-4	4-3	2
Oxygen as COOH (% Wt)	13-10	5-0	0	0
Oxygen as OH^- (% Wt)	15-10	12-3	3-0	0
No. of Aromatic Groups per Layer	1-2	2	2-5	25
Volatile Matter (% Wt)	40-50	25-50	35-10	10
Contact Angle	0°	25°	45° Low Vol 50° High Vol	47° Anthr 60° Semi-Anth

Sources: Mishra et al. 1982, p.70.
Townsend 1985, p.55.

Table A2:2

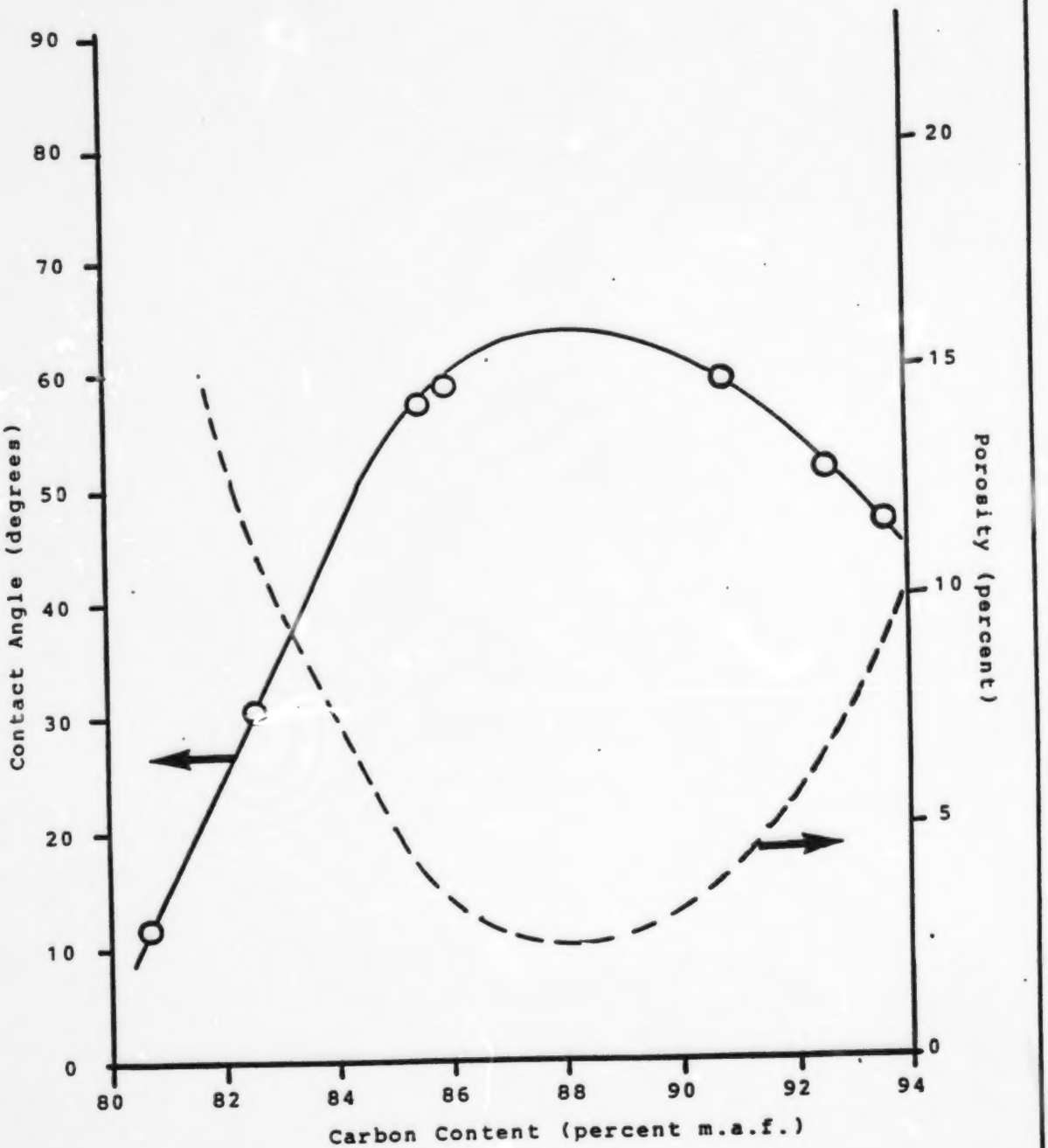
Frothers

Alcohol	Carbon Chain Length
Butyl	4
Amyl	5
Hexyl	6
Heptyl	7
Octyl	8
Methyl-isobutyl Carbinol (MIBC) (4 methyl - 2 pentanol)	6
2 ethyl hexanol (or 2 octanol)	8
Phenol	6
d-Cresol	6
x Napthol	10
B-Napthol	10
x Terpineol	10
Cyclomexanol	6
Diacetone alcohol (4 hydroxyl - 4 Methyl - 2 pentone)	6

Ether	Number Available
Polyoxypropylene Glycols	At least 4
Polyoxethylene Glycols	At least 8

Source: Townsend 1985, p.36

FIGURE A2:1 COMPARISON OF THE RELATIONSHIPS OF POROSITY AND HYDROPHOBICITY TO THE CARBONIFICATION OF THE COAL



Source: Wheeler and Keys 1987, p10.

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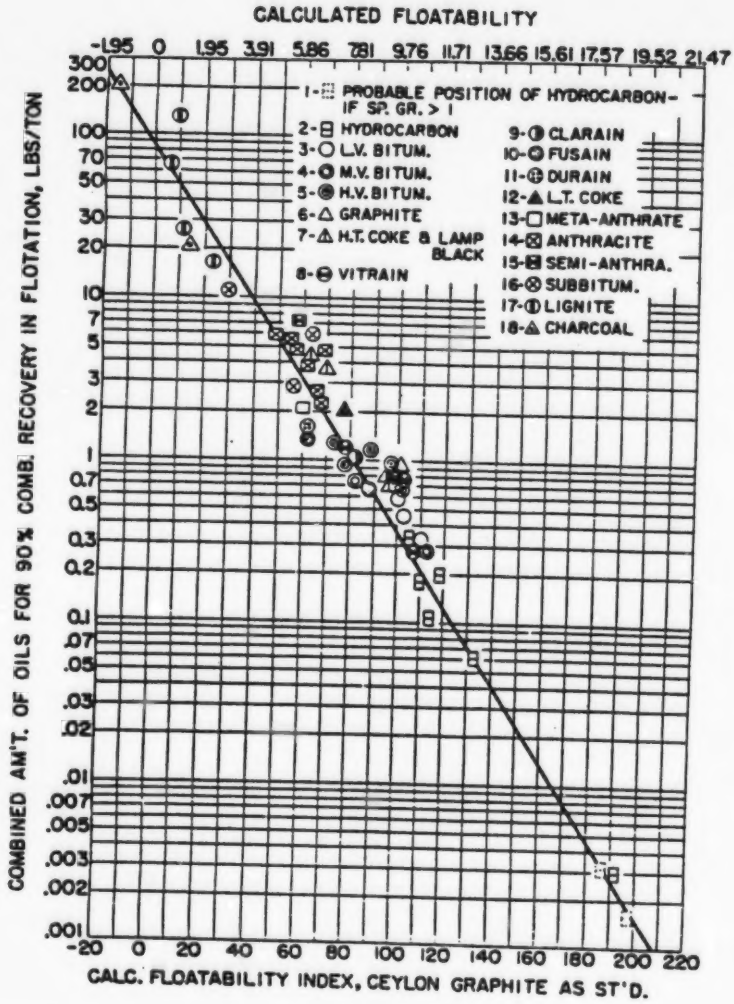

Figure A2:2 Correlation between the actual floatability and the calculated floatability index of coals, cokes and hydrocarbon minerals[15]

Source: Tsai 1982, p.218

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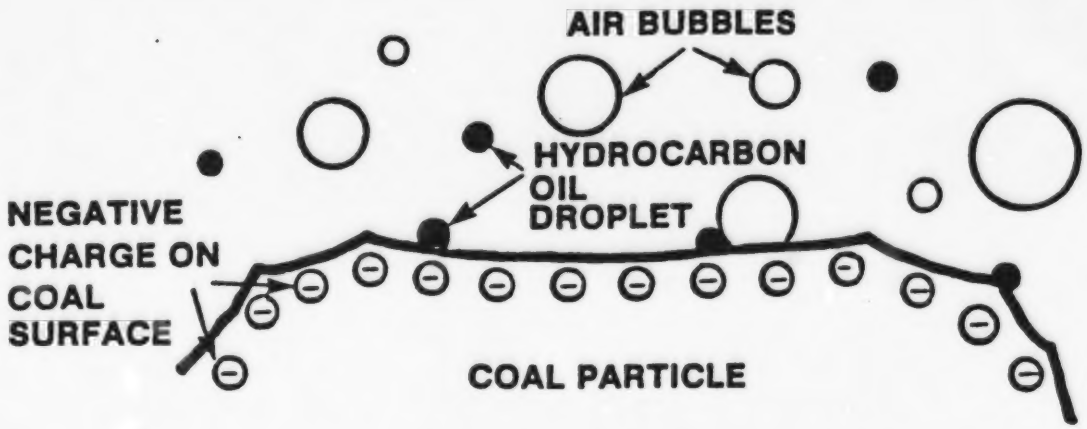
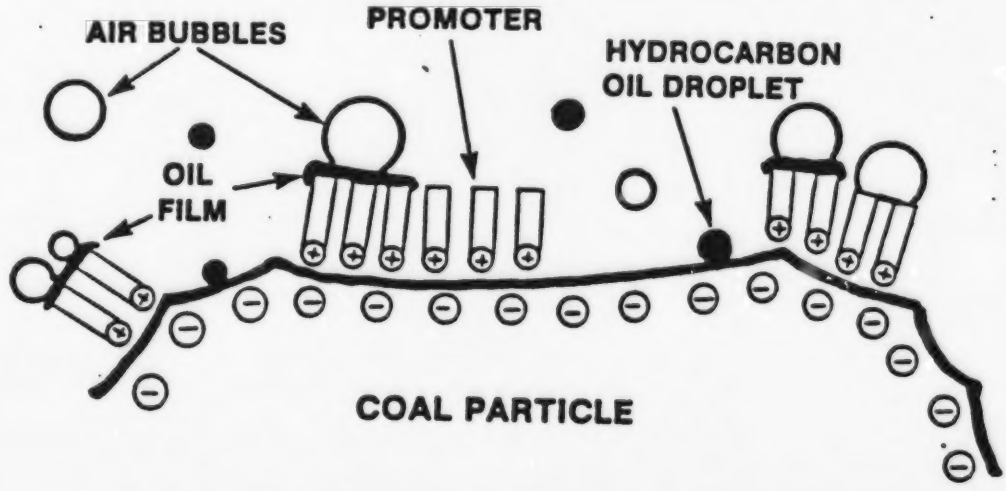
FIGURE A2:3 AN EXPLANATION OF THE FUNCTION OF A PROMOTER



A. LOW RANK HYDROPHYLIC COAL PARTICLE THAT IS NOT SIGNIFICANTLY ATTRACTIVE TO EITHER NEUTRAL HYDROCARBON OIL DROPLETS OR AIR BUBBLES.



B. SAME PARTICLE WITH PROMOTER CREATING HYDROPHOBIC SURFACE ATTRACTIVE TO BOTH NEUTRAL HYDROCARBON OIL AND AIR BUBBLES.

Source: Wheeler and Keys 1987, p.6

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Appendix 3

Standard Experimental Procedures

STANDARD PROCEDURE FOR FROTH FLOTATION EXPERIMENTS

1. Fill flotation cell with 2.9 litres of water.
2. Add 150 g coal sample.
3. Turn on impeller, adjust to desired speed, and pre-condition for three minutes.
4. Add reagents, by micro-syringe or pipette.
5. Condition the coal with reagents for four minutes.
6. After the four minutes of conditioning turn on the air.
7. For the first 30 seconds with air collect any product that flows out of the cell of its own accord.
8. Begin paddling after the 30 seconds of step 7. Continue paddling for 30 seconds and add this concentrate to the step 7 concentrate. This combined concentrate was called concentrate #1.
9. Continue paddling for an additional 30 seconds and keep concentrate separate: concentrate #2.
10. Continue paddling for an additional 30 seconds and keep concentrate separate: concentrate #3.
11. Continue paddling for an additional 90 seconds and keep concentrate separate: concentrate #4.
12. Stop test.
13. Collect and weigh the four concentrates and the tailings, allow to settle, decant, dry, and analyse.
14. Determine the pH from the supernatant liquid decanted from the settled tailings.

Thus, as a result of this procedure four concentrate samples and one tailings sample were produced for each test:

Concentrate #1 : First 30 seconds of free flow plus next 30 seconds with paddling.
Concentrate #2 : Next 30 seconds with paddling
Concentrate #3 : Next 30 seconds with paddling
Concentrate #4 : Next 90 seconds with paddling
Tailings

STANDARD PROCEDURE FOR OIL AGGLOMERATION EXPERIMENTS

1. Fill agglomerating vessel with 500 ml of water.
2. Add 25 g of minus 0.15 mm (100 mesh) coal.
3. Condition coal for three minutes, low setting.
4. Add agglomerating oil by means of pipette or syringe.
5. Agitate at low setting for 30 seconds.
6. Agitate at high setting for 60 seconds.
7. Agitate at low setting for 90 seconds.
8. Stop test.
9. Pour contents onto stationary 0.15 mm opening sieve (100 mesh).
10. Allow concentrate trapped on sieve to drain for one minute.
11. Wash concentrate and tailings into separate containers, allow to settle, decant, dry, weigh and analyse.
12. Determine pH of liquid decanted from settled tailings.

Thus, for all standard agglomeration tests a single concentrate and a single tailings were created and analysed.

STANDARD PROCEDURE FOR AGGLOMERATION FLOTATION EXPERIMENTS

1. Place 150 g of coal and 500 ml of water in agglomerating vessel.
2. Condition for three minutes.
3. Add collector by means of syringe or pipette.
4. Agitate at low shear for 60 seconds, high shear for 120 seconds, and low shear for 180 seconds.
5. Transfer contents of agglomerating vessel to flotation cell.
6. Dilute to 5% pulp density.
7. Turn on impeller and add frother.
8. Condition for 30 seconds.
9. Turn on air.
10. Collect free flowing froth for 30 seconds.
11. Paddle for an additional 180 seconds, to produce a single concentrate (inclusive of concentrate from step 10).
12. Turn off flotation cell.
13. Dry and analyse concentrate and tailings.

EXAMPLE ILLUSTRATING THE CALCULATION OF ASH CONTENT OF AGGLOMERATES

		wt (gm)	Ash %	
Feed:	coal	25.0	33.0	(assumed)
	Bridging Liquid (Bunker C)	4.0	0	
Products:	Concentrates	19.91	11.3	(determined dB)
	Rejects	6.78	79.1	(determined dB)

Total Materials Collected

= 19.91 + 6.78

= 26.69 gm

Total Theoretical Ash % of Products

= 33.0%

Total Ash % of Products Determined

= 28.5%

((19.91 x 11.3) + (6.78 x 79.1)) ÷ (19.91 + 6.78)

= 28.5

Total Products Derived from Coal

= 23.05 gm

= 28.5/33.0 x 26.69

= 23.05

Note: 25 g of wet coal (1.5% moisture) added and 23.05 g dB recovered. Major cause for discrepancy is assumption of 25 g of feed. Material losses during experimentation were negligible.

Total Oil Collected on Products

= 3.64 gm

= 26.69 - 23.05

= 3.64

Distribution of Oil to Concentrates and Rejects
(Inversely Proportional to Ash Content)

Reject Ash Determined/Concentrate Ash Determined
= 79.1/11.3
= 7/1

Oil Component in Reject
= 1/8 x 3.64
= 0.46 gm

Oil Component in Clean Coal
= 7/8 x 3.64
= 3.18 gm

Actual wt. of Agglomerate
= 19.91 - 3.18
= 16.73 gm

Actual Ash % of Agglomerate
= 19.91/16.73 x 11.3
= 13.45%

Actual wt. of Reject
= 6.78 - 0.46
= 6.32 gm

Actual Ash % of Reject
= 6.78/6.32 x 79.1
= 84.85%

Appendix 4

Experimental Data

Table A4:1
Flotation

Test No.	Non-Standard Conditions	Cumulative Concentrate Analyses								Tailings		Feed	Carbon
		30 Sec		60 Sec		90 Sec		180 Sec		YLD	ASH	Reconst	Recovery
		YLD %	ASH %	YLD %	ASH %	YLD %	ASH %	YLD %	ASH %	%	%	ASH %	%
1A	0 kg/t Frother: 0 kg/t Collector	0.5	19.7	1.0	20.6	1.5	20.8	2.4	20.9	97.6	20.5	20.5	2.4
1B		0.8	20.8	1.2	21.3	1.7	21.5	2.8	21.6	97.2	20.6	20.6	2.8
2A	0.1 kg/t MIBC: 0 kg/t Collector	0.4	19.9	0.8	20.2	1.2	20.4	1.8	20.8	98.2	19.9	19.9	1.8
2B		0.5	20.9	0.8	21.3	1.1	21.4	1.9	21.8	98.1	20.5	20.5	1.9
3A	0.2 kg/t MIBC: 0 kg/t Collector	0.8	20.8	1.3	21.1	1.8	21.4	2.8	21.4	97.2	22.5	22.4	2.8
3B		0.5	18.9	1.0	19.8	1.3	20.1	2.4	20.7	97.6	22.1	22.0	2.4
4A	0.3 kg/t MIBC: 0 kg/t Collector	2.5	18.6	3.4	18.2	4.4	18.2	6.5	18.1	93.5	20.6	20.5	6.7
4B		2.7	18.2	3.9	17.9	5.1	17.9	7.1	17.7	92.9	22.2	21.9	7.4
5A	0.25 kg/t Diesel	6.9	10.4	9.9	10.6	11.3	10.8	13.5	11.6	86.5	23.2	21.6	15.2
5B		6.5	10.7	8.9	10.6	10.5	11.0	12.6	11.7	87.4	22.9	21.5	14.2
6A	0.50 kg/t Diesel	12.1	8.2	16.1	8.2	18.4	8.4	21.6	9.0	78.4	24.4	21.0	24.9
6B		11.7	7.9	16.4	8.1	19.2	8.4	22.4	9.0	77.6	24.8	21.3	25.8
7A	1.00 kg/t Diesel	19.0	6.7	27.8	6.6	32.7	6.8	42.6	7.2	57.4	31.7	21.2	50.2
7B		16.8	6.8	24.6	6.7	31.3	6.7	39.1	7.0	60.9	29.7	20.9	45.9
7C		17.8	7.1	26.1	7.0	31.4	7.0	37.5	7.6	62.5	30.4	21.8	44.4
7D		18.5	7.1	26.6	7.0	31.0	7.2	37.0	7.7	63.0	29.8	21.6	43.5
7E		17.2	7.8	22.5	7.9	26.5	8.1	31.0	8.6	69.0	26.9	21.3	36.0
7F		14.5	7.6	21.7	7.4	27.8	7.6	34.6	8.0	65.4	28.1	21.2	40.3
8A	1.75 kg/t Diesel	22.2	6.5	34.8	6.7	41.9	6.8	52.6	7.3	47.4	36.4	21.1	61.8
8B		26.3	6.8	37.7	6.9	43.1	7.0	51.2	7.4	48.8	35.6	21.2	60.1
9A	2.50 kg/t Diesel	43.4	7.2	51.1	7.3	55.8	7.5	59.8	8.0	40.2	41.1	21.3	69.9
9B		38.1	7.2	48.9	7.3	55.1	7.4	59.2	7.9	40.8	41.2	21.5	69.4
10A	5.00 kg/t Diesel	50.4	7.7	62.7	8.0	67.6	8.2	71.3	8.7	28.7	53.1	21.4	82.9
10B		49.1	7.8	61.2	8.0	67.0	8.2	70.9	8.7	29.1	52.4	21.4	82.3
11A	1.00 kg/t Kerosene	23.6	7.3	30.2	7.2	33.1	7.3	35.1	7.8	64.9	28.3	21.1	41.1
11B		27.9	7.0	34.1	7.0	36.0	7.1	37.7	7.6	62.3	29.7	21.4	44.3
12	1.00 kg/t Varsol	7.6	17.1	9.4	17.3	10.7	17.2	13.4	16.7	86.6	22.4	21.7	14.3
13	5.00 kg/t Varsol	50.3	8.1	53.0	8.4	54.3	8.7	56.3	9.1	43.7	37.6	21.5	65.3
14A	pH 5	18.0	7.4	27.6	7.1	34.1	7.1	41.6	7.4	58.4	30.4	20.8	48.7
14B		19.7	7.7	27.3	7.5	33.1	7.5	40.1	7.6	59.9	30.4	21.3	47.1

Table A4:1
Continued

Test No.	Non-Standard Conditions	Cumulative Concentrate Analyses								Tailings		Feed	Carbon
		30 Sec		60 Sec		90 Sec		180 Sec		YLD	ASH	Reconst	Recovery
		YLD %	ASH %	YLD %	ASH %	YLD %	ASH %	YLD %	ASH %	%	%	ASH %	%
15A	pH 9	12.4	9.0	18.7	8.5	22.9	8.4	30.1	8.3	69.9	27.4	21.6	35.2
15B		13.1	8.8	19.0	8.3	23.7	8.1	29.8	8.3	70.2	27.0	21.5	34.8
16A	0 min Conditioning	13.9	7.4	21.1	7.0	27.1	6.9	35.6	7.1	64.4	29.4	21.5	42.1
16B		15.4	6.2	23.2	6.3	29.4	6.4	37.7	6.7	62.3	29.9	21.1	44.6
17A	2 min Conditioning	13.3	7.1	20.8	7.0	25.7	7.0	33.2	7.3	66.8	28.4	21.4	39.1
17B		14.7	6.8	24.2	6.9	29.9	7.1	36.3	7.5	63.7	29.4	21.4	42.8
18A	6 min Conditioning	15.8	7.1	23.4	7.2	28.2	7.3	33.4	7.7	66.6	28.8	21.8	39.4
18B		13.8	7.4	20.0	7.4	24.7	7.4	30.3	7.7	69.7	26.9	21.1	35.5
19A	10% Pulp Density	22.3	7.0	30.1	7.2	33.9	7.3	40.0	7.5	60.0	30.3	21.2	47.0
19B		21.9	7.2	29.0	7.2	33.7	7.3	40.6	7.5	59.4	29.9	20.8	47.4
20A	15% Pulp Density	25.1	7.5	29.4	7.5	32.7	7.6	37.5	7.7	62.5	28.6	20.8	43.6
20B		27.1	7.6	31.3	7.7	34.3	7.8	39.1	8.0	60.9	29.5	21.1	45.6
21A	0.3 kg/t Shur-coal 168	19.4	6.9	35.6	6.9	47.7	7.2	68.0	8.3	32.0	48.9	21.3	79.2
21B		20.7	7.4	34.8	7.2	46.1	7.4	64.8	8.2	35.2	45.9	21.5	75.7
22A	0.3 kg/t Shur-coal 164	22.0	7.4	33.8	7.2	43.8	7.4	64.7	8.1	35.3	44.9	21.1	75.4
22B		18.3	8.0	32.5	7.4	43.7	7.5	64.8	8.2	35.2	44.7	21.0	75.4
23A	0.3 kg/t Shur-coal 2057	10.9	8.1	19.1	7.4	24.0	7.3	30.8	7.4	69.2	27.3	21.2	36.1
23B		11.9	8.1	17.5	7.6	21.9	7.4	26.2	7.7	73.8	26.3	21.4	30.8
24A	0.3 kg/t Shur-coal EPSC	15.0	7.6	24.5	7.2	37.0	7.1	64.2	8.3	35.8	44.9	21.4	74.9
24B		16.3	7.7	29.1	7.1	39.2	7.3	62.8	8.3	37.2	42.8	21.2	73.0
25A	0.3 kg/t Aerofroth 88	15.8	7.3	24.4	7.1	31.3	7.0	44.3	7.3	55.7	31.8	21.0	51.9
25B		14.3	7.5	23.0	7.0	31.0	7.0	43.2	7.4	56.8	31.5	21.1	50.7
26	900 rpm, 340 L air/hr	8.6	5.2	11.9	5.8	13.1	6.2	15.1	7.1	84.9	24.4	21.8	18.0
27	1200 rpm, 340 L air/hr	20.1	7.8	27.6	7.9	32.1	8.0	36.2	8.5	63.8	29.3	21.8	42.3
28	1500 rpm, 225 L air/hr	22.1	8.3	29.2	9.7	32.0	10.2	38.9	11.6	61.1	27.5	21.4	43.7
29A	Constant Level	17.8	6.7	28.8	6.8	34.5	7.1	41.1	8.0	58.9	30.0	20.9	47.9
29B		16.6	6.8	26.3	6.9	34.1	7.1	42.3	7.8	57.7	30.8	21.1	49.4
30A	0.6 x 0.15, Constant Level	7.4	4.0	23.5	4.3	39.3	5.0	70.8	6.9	29.2	36.0	15.4	77.9
30B		8.5	4.0	21.3	4.2	34.1	4.5	69.0	6.4	31.0	34.3	15.1	76.0
31A	0.15 x 0, Constant Level	24.7	10.9	31.1	11.5	34.4	11.8	38.4	13.1	61.6	42.8	31.4	48.6
31B		22.9	11.4	29.8	11.8	32.7	12.2	37.0	13.5	63.0	41.5	31.1	46.5

Table A4:1

Continued

Test No.	Non-Standard Conditions	Cumulative Concentrate Analyses								Tailings		Feed	Carbon
		30 Sec		60 Sec		90 Sec		180 Sec		YLD	ASH	Reconst	Recovery
		YLD %	ASH %	YLD %	ASH %	YLD %	ASH %	YLD %	ASH %	%	%	ASH %	%
32A	15% Pulp Density, Constant Level	28.1	7.7	35.9	7.9	40.2	8.2	46.4	9.6	53.6	31.8	21.5	53.5
32B		29.4	7.8	37.3	8.0	42.0	8.2	47.1	9.5	52.9	31.2	21.0	54.0
33A	15% Pulp., Const. Level, 0.1 kg/t MIBC	7.2	8.9	9.9	9.1	11.3	9.3	13.5	9.8	86.5	23.3	21.5	15.6
33B		8.3	8.8	11.2	8.6	13.3	8.9	15.3	9.2	84.7	22.9	20.8	17.6
34	0.3 kg/t EPSC, 5.0 kg/t Diesel	61.8	8.6	73.0	9.2	76.7	9.7	79.2	10.2	20.8	62.7	21.1	90.1
35	0.3 EPSC, 0.15 x 0, 5.0 kg/t Diesel	62.4	13.1	66.4	13.8	68.1	14.3	70.3	14.9	29.7	71.0	31.5	87.4
36	0.3 EPSC, 0.6 x 0.15, 5.0 kg/t Diesel	7.6	8.7	11.3	8.2	15.1	7.9	20.9	7.6	79.1	17.3	15.3	22.8
37	0.3 EPSC, 0.6 x 0.15, 0.1 kg/t Diesel	60.5	6.2	64.2	6.4	65.6	6.5	67.3	6.6	32.7	34.9	15.8	74.7
38	Scavenge No. 37 (Note 1)	60.5	6.2	64.2	6.4	65.6	6.5	75.1	7.2	24.9	41.9	15.8	82.8
39	0.3 EPSC, 0.15 x 0, 2.28 kg/t Diesel	61.6	13.6	65.3	14.2	66.9	14.6	68.7	15.1	31.3	67.6	31.5	85.2
40	0.3 EPSC, 0.15 x 0, 12.67 kg/t Diesel	67.8	14.6	70.7	15.2	72.3	15.8	74.4	16.6	25.6	75.2	31.6	90.7
41	0.3 EPSC, 0.6 x 0.15, 0.2 kg/t Diesel	66.8	6.9	72.5	7.2	74.6	7.3	76.8	7.4	23.2	42.5	15.6	84.2

Standard Conditions: 0.3 kg/t MIBC, 1.00 kg/t Diesel, 5% Pulp Density, pH 7.3, 4 min. Conditioning Time, 1200 rpm, 225 L air/hr, Decreasing water level.

Note 1: 0.1 kg/t diesel (based on initial sample weight of test 37) were added to the tailings of test no. 37. A single concentrate was taken during 180 sec. of froth collection. This concentrate was added, mathematically, to the 180 sec. concentrate of test no. 37.

Table A4:2

Test No.	Non-Standard Conditions	Concentrate Yield %	Concentrate Ash %	Tailings Yield %	Tailings Ash %	Feed Reconst Ash %	Carbon Recovery %
	Tests Using 0.15 x 0 mm Feed, 0.15 mm Opening Concentrate Screen						
1A	10 kg/t Diesel	45.9	17.6	54.1	46.6	33.3	56.7
1B		43.2	16.5	56.8	46.4	33.5	54.2
2A	20 kg/t Diesel	47.2	15.3	52.8	49.4	33.3	59.9
2B		46.1	16.2	53.9	48.5	33.6	58.2
3A	40 kg/t Diesel	50.7	14.1	49.3	51.4	32.5	64.5
3B		52.2	15.2	47.8	52.9	33.2	66.3
4A	80 kg/t Diesel	66.7	15.3	33.3	65.7	32.1	83.2
4B		62.8	16.2	37.2	61.9	33.2	78.8
5A	120 kg/t Diesel	69.1	16.7	30.9	66.9	32.2	84.9
5B		64.0	16.2	36.0	63.3	33.1	80.3
6A	160 kg/t Diesel	68.5	17.6	31.5	66.4	33.0	84.2
6B		72.0	17.6	28.0	69.3	32.1	87.3
7A	200 kg/t Diesel	72.7	17.6	27.3	69.7	31.8	87.9
7B		69.7	16.0	30.3	69.3	32.1	86.3
8A	160 kg/t Bunker C	74.6	11.3	25.4	79.1	28.5	92.6
8A	Br. Liq. Free Basis	71.8	13.5	28.2	82.4	32.9	92.6
8B		73.4	13.6	26.6	72.2	29.2	89.6
8B		71.3	15.8	28.7	75.7	33.0	89.6
9A	200 kg/t Bunker C	78.1	15.2	21.9	75.9	28.5	92.6
9A	Br. Liq. Free Basis	75.8	18.2	24.2	79.6	33.0	92.6
9B		79.4	13.8	20.6	81.7	27.8	94.8
9B		76.5	17.0	23.5	85.1	33.0	94.8
10	Re-Aggl. 9B	74.1	8.9	25.9	81.7	27.8	93.4
10	Br. Liq. Free Basis	70.4	11.1	29.6	85.1	33.0	93.4
11A	200 kg/t Varsol	72.3	16.9	27.7	75.3	33.1	89.8
11B		68.1	17.9	31.9	63.1	32.4	82.6
12A	pH5	60.8	15.3	39.2	60.8	33.1	77.0
12B		63.2	16.3	36.8	62.3	33.2	79.2

Table A4:2
Continued

Test No.	Non-Standard Conditions	Concentrate		Tailings		Feed	Carbon
		Yield %	Ash %	Yield %	Ash %	Reconst Ash %	Recovery %
13A	pH7	60.7	15.0	39.3	60.8	33.0	77.0
13B		60.3	14.9	39.7	60.8	33.1	76.8
14A	pH 9	64.6	16.8	35.4	62.9	33.1	80.4
14B		61.6	15.5	38.4	61.4	33.1	77.9
15A	30 sec. at 1000 rpm	66.4	20.7	33.6	57.5	33.0	78.7
15B		64.6	20.8	35.4	55.2	33.0	76.3
16A	180 sec. at 1000 rpm	55.1	16.1	44.9	54.4	33.3	69.3
16B		68.9	20.1	31.1	60.9	32.8	81.9
17A	30 sec. at 15000 rpm	74.7	23.4	25.3	63.4	33.5	86.1
17B		62.6	18.8	37.4	57.4	33.2	76.2
18A	180 sec. at 15000 rpm	61.2	15.9	38.8	60.6	33.3	77.1
18B		70.8	19.2	29.2	68.5	33.6	86.1
19A	200 kg/t Diesel, 10% Pulp Density	70.9	17.6	29.1	64.9	31.4	85.1
19B		66.3	15.4	33.7	65.8	32.3	83.0
20A	200 kg/t Diesel, 15% Pulp Density	72.8	19.0	27.2	66.2	31.9	86.5
20B		77.8	21.7	22.2	66.4	31.6	89.1
21	Re-Aggl. No 20B	63.0	13.2	37.0	63.0	31.6	80.0
22	Re-Aggl. No 21	56.9	9.6	43.1	60.7	31.6	75.2
23A	160 kg/t Bunker C, Re-Aggl. Once	65.4	8.0	34.6	71.1	29.8	85.7
23A	Br. Liq. Free Basis	63.2	9.1	36.8	74.0	33.0	85.7
23B		66.8	9.1	33.2	70.1	29.3	85.9
23B		64.3	10.6	35.7	73.6	33.1	85.9
24A	160 kg/t Bunker C, Wash Conc. 500 ml H_2O	69.1	9.8	30.9	72.0	29.0	87.8
24A	Br. Liq. Free Basis	66.5	11.5	33.5	75.6	33.0	87.8
24B		68.3	8.8	31.7	72.9	29.1	87.9
24B		65.7	10.4	34.3	76.4	33.1	87.9
25A	180 kg/t Bunker C	76.3	13.7	23.7	69.4	26.9	90.1
25A	Br. Liq. Free Basis	73.2	17.5	26.8	75.3	33.0	90.1
25B		77.9	10.1	22.1	76.3	24.7	93.0
25B		72.8	14.4	27.2	82.8	33.0	93.0
25C		79.4	11.8	20.6	74.9	24.7	93.1
25C		74.8	16.7	25.2	81.7	33.1	93.1

Table A4:2

Continued

Test No.	Non-Standard Conditions	Concentrate		Tailings		Feed	Carbon
		Yield %	Ash %	Yield %	Ash %	Reconst Ash %	Recovery %
26A	180 kg/t Bunker C, Re-Aggl. 140 kg/t Coal Tar	69.0	5.7	31.0	73.4	26.6	88.8
26A	Br. Liq. Free Basis	64.3	7.5	35.7	78.9	33.0	88.8
26B	Re-Aggl. No. 25A, 140 kg/t Coal Tar	67.0	7.0	33.0	67.2	26.9	85.2
26B	Br. Liq. Free Basis	62.8	9.1	37.2	73.3	33.0	85.2
27A	Re-Aggl. No 25B, 200 kg/t Coal Tar	72.4	6.4	27.6	72.8	24.7	90.0
27A	Br. Liq. Free Basis	66.6	9.3	33.4	80.0	32.9	90.0
27B	Re-Aggl. No 25C, 200 kg/t Coal Tar	72.6	6.7	27.4	72.6	24.7	90.0
27B	Br. Liq. Free Basis	66.8	9.8	33.2	79.9	33.1	90.0
28	120 kg/t Diesel, Re-Aggl., 40 kg/t Coal Tar	60.9	12.3	39.1	63.4	32.2	78.9
28	Br. Liq. Free Basis	60.5	12.7	39.5	64.2	33.0	78.9
29	120 kg/t Coal Tar, Re-Aggl. Once	38.2	8.3	61.8	45.2	31.1	50.8
29	Br. Liq. Free Basis	37.4	9.0	62.6	47.4	33.1	50.8
30	400 kg/t (10% Toluene - 90% Coal Tar), Re-Aggl. Once	86.6	17.8	13.4	78.8	26.0	96.2
30	Br. Liq. Free Basis	84.0	23.3	16.0	84.0	33.0	96.2
31	Agglomerate Using Flotation Cell, 2000 rpm	65.6	19.7	34.4	58.4	33.0	78.6
	Tests Using 0.6 x 0 mm Feed, 0.85 mm Opening Screen For Concentrate Recovery						
32	No Bridging Liquid	19.5	15.4	80.5	23.5	21.9	21.1
33	20 kg/t Diesel	72.2	16.9	27.8	36.9	22.5	77.4
34	100 kg/t Diesel	66.5	13.3	33.5	38.7	21.8	73.7
35	20 kg/t Husky	71.0	16.8	29.0	33.9	21.8	75.5
35	Br. Liq. Free Basis	71.0	16.8	29.0	33.9	21.8	75.5
36	100 kg/t Husky	64.9	15.2	35.1	29.5	20.2	69.0
36	Br. Liq. Free Basis	64.7	16.0	35.3	30.8	21.2	69.0
37	40 kg/t Husky + 30 kg/t Bunker C	82.8	10.6	17.2	67.0	20.3	92.9
37	Br. Liq. Free Basis	82.3	11.2	17.7	68.4	21.3	92.9

Table A4:2

Continued

Test No.	Non-Standard Conditions	Concentrate		Tailings		Feed	Carbon
		Yield %	Ash %	Yield %	Ash %	Reconst Ash %	Recovery %
	Tests Using 0.6 x 0 mm Feed, 0.15 Opening Screen For Concentrate Recovery						
38	No Bridging Liquid	63.3	9.5	36.7	41.0	21.1	72.6
39A	10 kg/t Diesel	75.1	11.1	24.9	54.3	21.8	85.5
39B		76.2	11.2	23.8	53.8	21.4	86.0
40A	20 kg/t Diesel	77.0	10.4	23.0	57.1	21.1	87.5
40B		77.5	11.2	22.5	57.3	21.6	87.7
41A	10 kg/t Bunker C	80.8	13.3	19.2	56.8	21.6	89.4
41B		70.9	11.4	29.1	45.1	21.2	79.7
42	200 kg/t Diesel, 10% Pulp Density	89.1	14.4	10.9	74.1	20.9	96.4
43	Re-Aggl. No. 42	83.6	10.8	16.4	72.3	20.9	94.2
44	80 kg/t Bunker C	87.5	9.7	12.5	73.0	17.6	95.9
44	Br. Liq. Free Basis	85.7	12.0	14.3	77.5	21.3	95.9
45	Re-Aggl. No 44, 120 kg/t Coal Tar	84.0	6.9	16.0	73.8	17.6	94.9
45	Br. Liq. Free Basis	81.7	8.6	18.3	78.2	21.3	94.9
46	40 kg/t Bunker C + 80 kg/t Coal Tar	85.3	10.4	14.7	64.2	18.4	93.5
46	Br. Liq. Free Basis	83.9	12.3	16.1	68.4	21.4	93.5
47	Re-Aggl. No 46, 80 kg/t Coal Tar, Screen 0.85 mm	61.0	8.2	39.0	34.2	18.4	68.6
47	Br. Liq. Free Basis	59.8	9.8	40.2	38.6	21.4	68.6

Table A4:3

Aggiomeration Flotation

Test No.	Non-Standard Conditions	Concentrate		Tailings		Feed	Carbon
		Yield %	Ash %	Yield %	Ash %	Reconst Ash %	Recovery %
1	0.6 x 0 mm, 1.0 kg/t Diesel	42.9	12.1	57.1	28.4	21.4	47.9
2	0.6 x 0 mm, 5.0 kg/t Diesel	84.7	11.9	15.3	77.6	21.9	95.6
3A	0.6 x 0 mm, 10.0 kg/t Diesel	85.9	11.7	14.1	84.6	22.0	97.2
3B		86.5	12.8	13.5	83.7	22.3	97.2
4A	0.6 x 0 mm, 20.0 kg/t Diesel	86.3	10.9	13.7	85.1	21.1	97.4
4B		86.8	11.0	13.2	86.4	20.9	97.7
5	0.6 x 0 mm, 5.0 kg/t Bunker C	81.6	11.1	18.4	68.3	21.6	92.5
6	0.6 x 0 mm, 10.0 kg/t Bunker C	87.7	12.6	12.3	86.9	21.8	97.9
7A	0.15 x 0 mm, 10.0 kg/t Diesel	75.5	17.5	24.5	80.8	33.0	93.0
7B		76.5	18.2	23.5	80.9	32.9	93.3
8A	0.15 x 0 mm, 20.0 kg/t Diesel	76.9	18.3	23.1	80.7	32.7	93.4
8B		77.2	18.2	22.8	83.6	33.1	94.4